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Crushed Stone

Monsanto Research Corp, Dayton, Ohio

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This report describes a study of atmospheric emissions from the crushed stone industry. Atmospheric emissions of respirable particulates (<7μm) occur in the mining from the open quarry and in the processing at the crushing and screening plant. The emission factor for respirable particulates from the entire facility is 3.25 g/metric ton ±2.54 g/metric ton at the 95% confidence level. Free silica comprises 1.6% of these particulates by weight. The primary crusher and quarrying unit operations account for 73.5% of the respirable particulates. The emission factor for total particulates is 28.4 g/metric ton ±24.5 g/metric ton at the 95% confidence limit. In order to evaluate the potential environmental effect of crushed stone plants, a severity factor was defined as the ratio of the maximum ground level concentration of an emission to the ambient air quality standard for criteria pollutants and to a modified threshold limit value for other pollutants. The maximum factors for a representative crushed stone plant are 0.03 and 0.83 when the emissions are treated as respirable particulates and free silica, respectively. Total particulate emissions from crushed stone production account for no more than 0.02% of the total national particulate emissions. No emerging technology of specific importance to air pollution control in the crushed stone industry was found in this study.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from the crushed stone industry. This study was conducted to provide sufficient information for EPA to ascertain the need for developing control technology in this industry. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Water Act and solid waste legislation. If control technology is unavailable, inadequate, uneconomical or socially unacceptable, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number (>500) of operations in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL. This report contains the data necessary to make that decision for the crushed stone industry.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries which represent sources of pollution in accordance with EPA's responsibility as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. This study of crushed stone was initiated by IERL-Research Triangle Park in March 1975; Mr. David K. Oestreich served as EPA Project Leader. The project was transferred to the Resources Extraction and Handling Division, IERL-Cincinnati, in October 1975; Mr. John F. Martin served as EPA Project Leader through completion of the study.

ABSTRACT

This report describes a study of air emissions from crushed stone production. The potential environmental effect of the source is evaluated.

Crushed stone production in 1972 was 1.07×10^8 metric tons (1.18×10^8 tons), 68% of which was traprock. Contingency forecasts of increased crushed stone demand in the year 2000 range from 300% to 490% of 1968 levels.

Atmospheric emissions of respirable particulates (<7 μm) occur in the two areas of operation: mining from the open quarry, and processing at the crushing and screening plant. The emission factor for respirable particulates from the entire facility is 3.25 g/metric ton (0.007 lb/ton) ±2.54 g/metric ton (0.005 lb/ton) at the 95% confidence level. Free silica comprises 1.6% of these particulates by weight. The primary crusher and quarrying unit operations account for 73.5% of the respirable particulates. The emission factor for total particulates is 28.4 g/metric ton (0.57 lb/ton) ±24.5 g/metric ton (0.049 lb/ton) at the 95% confidence limit.

In order to evaluate the potential environmental effect of crushed stone plants, a severity factor was defined as the ratio of the maximum ground level concentration of an emission to the ambient air quality standard for criteria pollutants and to a modified threshold limit value for other pollutants. The maximum severity factors for a representative crushed stone plant are 0.03 and 0.83 when the emissions are treated as respirable particulates and free silica, respectively.

The population affected above a severity of 0.1 is zero for respirable particulates and 172 persons for free silica particulates. Total particulate emissions from crushed stone production account for no more than 0.02% of the total national particulate emissions.

No emerging technology of specific importance to air pollution control in the crushed stone industry was found in this study.

This report was submitted in partial fulfillment of Contract No. 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period March 1975 to February 1976, and work was completed as of July 1977.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A'	-- cross-sectional area of falling granules
A, D, E, F	-- specific distances for high volume samplers from x axis
b	-- width of a conveyor belt
D	-- representative distance from the source
D_f	-- diameter of a fiber
D_S	-- distance at which the source severity equals 0.1
D_t	-- dosage
E	-- emission factor
E_d	-- emission factor for drilling operation
E_l	-- emission factor for loading operation
E_R	-- emission factor for respirable particulate
E_u	-- emission factor for unloading operation
exp	-- natural log base, e = 2.72, a constant
g	-- gravitational acceleration
H	-- height of material fall
m_1, m_2	-- slopes used in calculating distances to samplers
m'	-- conveyor belt load
M	-- model used for field data
N	-- number of sampler readings
P	-- production rate of crushed stone
Q	-- emission rate
Q_i	-- initial airflow rate
Q_f	-- final airflow rate
R, R_d	-- amount of respirable dust formed
R'	-- filtration area divided by counting field area
S	-- source severity
S_p	-- severity of free silica particulate
S'	-- atmospheric stability class
S_0, S_1, S_2, S_3, S_4	-- high volume sampler locations
S_n	-- n-th high volume sampler locations

t_s	-- sampling time
TLV	-- threshold limit value
u	-- mean wind speed
U_b	-- linear speed of a conveyor belt
V, V_a	-- air volume sampled
W_i	-- initial (tare) weight of filter
W_f	-- final weight of filter
x_i, y_i	-- Cartesian coordinates used to relate position of the ith sampler to the source
X, X_i	-- downwind distance from source along the dispersion centerline
X'	-- any average calculated value
Y, Y_i	-- lateral distance from dispersion centerline to sampler
Z	-- vertical distance from the X-Y plane of the source to the sampler plane

SYMBOLS

α	-- angle defined for use in calculating sampler positions
θ	-- wind azimuth angle with respect to y axis
π	-- a constant, 3.14
ρ_c	-- material density of coal
σ	-- overall standard deviation
σ_y	-- horizontal standard deviation of plume dispersion
σ_z	-- vertical standard deviation of plume dispersion
σ_1	-- estimated population standard deviation from sampling for χ
σ_2	-- additional standard deviation in calculation of Q from χ
χ	-- downwind concentration
χ_i	-- concentration at coordinate location (X_i, Y_i, 0)

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	to	Multiply by
centimeter (cm)	angstrom	1.000×10^{8}
centimeter^2 (cm^2)	inch^2	1.550×10^{-1}
centimeter^3 (cm^3)	inch^3	6.102×10^{-2}
degree Celsius (°C)	degree Fahrenheit	$t_{°F} = 1.8\ t_{°C} + 32$
kilogram (kg)	pound-mass (lb mass avoirdupois)	2.204
kilogram (kg)	ton (short, 2,000 lb mass)	1.102×10^{-3}
kilometer^2 (km^2)	mile^2	2.591
meter (m)	foot	3.281
meter (m)	mile	6.215×10^{-4}
meter^3 (m^3)	foot^3	3.531×10^{1}
meter^3 (m^3)	liter	1.000×10^{3}
meter/second (m/s)	miles/hr	2.237
metric ton	pound-mass	2.205×10^{3}
millimeter^2 (mm^2)	inch^2	1.550×10^{-3}
pascal (Pa)	pound-force/inch^2 (psi)	1.450×10^{-4}
radian (rad)	degree (°)	5.730×10^{1}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
kilo	k	10^{3}	1 kPa = 1×10^{3} pascals
centi	c	10^{-2}	1 cm = 1×10^{-2} meter
milli	m	10^{-3}	1 mg = 1×10^{-3} gram
micro	μ	10^{-6}	1 μm = 1×10^{-6} meter

[a] Metric Practice Guide. ASTM Designation E 380-74, American Society for Testing and Materials, Philadelphia, Pennsylvania, November 1974. 34 pp.

SECTION I

INTRODUCTION

The conversion of naturally occurring stone deposits into crushed stone involves mining from open quarries and processing for size reduction and classification. Air pollution is produced by individual sources (unit operations) during mining, processing, and material transfer activities.

An investigation of the crushed stone industry was conducted to provide a better understanding of the distribution and characteristics of the air pollution emissions than was available in the literature. Data collection emphasized the accumulation of sufficient information to ascertain the need for developing control technology.

This document contains information on:

- Emission sources and composition
- A method to estimate the emission levels due to crushed stone unit operations
- Geographical distribution of crushed stone facilities
- Hazard potential of emissions
- Severity of emissions
- Types of control technology used and proposed
- Trends in crushed stone production and their effects on emission levels

SECTION II

SUMMARY

The crushed stone industry converts naturally occurring stone deposits into a crushed stone form for use in the construction industry (81% of the output). Crushed stone, as interpreted in this study, includes: traprock, calcareous marl, shell marble, mica schist, slate, and other miscellaneous stone excluding granite, limestone, dolomite, sandstone, quartz, and quartzite. Dimension stones (stones $\geq$ 0.6 m in length and width) are also excluded. Traprock accounted for 68% of the crushed stone production of 1.07×10^8 metric tons[a] (1.18×10^8 tons) at 1,009 quarries in 1972. Contingency forecasts of increased crushed stone demand in the year 2000 range from 300% to 490% of 1968 levels.

Atmospheric emissions of respirable (<7-μm geometric mean diameter) particles occur from all individual (unit) operations. A crushed stone facility has two areas of operation: mining from the open quarry, and processing at the crushing and screening plant. The emission factor for respirable particles from the entire facility is 3.25 g/metric ton (0.007 lb/ton) ±2.54 g/metric ton (0.005 lb/ton) at the 95% confidence level. The primary crusher and quarrying unit operations account for 73.5% of the respirable particulate emissions. The only hazardous constituent of the emitted particles is free silica which comprises 1.6% by weight. Prolonged exposure to free silica may result in the development of a pulmonary fibrosis known as silicosis.

The emission factor for total particulates is 28.4 g/metric ton (0.057 lb/ton) ±24.5 g/metric ton (0.049 lb/ton) at the 95% confidence level. Nitrogen oxides and carbon monoxide are emitted by the blasting operation with respective emission factors of 2.85 g/metric ton (0.006 lb/ton) and 1.68 g/metric ton (0.003 lb/ton) of material blasted. Fibers are also emitted from all the unit operations with an emission factor of 128×10^6 fibers/metric ton (116×10^6 fibers/ton).

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[a] 1 metric ton = 10^6 grams = 2,205 pounds = 1.1 short tons (short tons are designated "tons" in this document;) other conversion factors and metric system prefixes are presented in the prefatory pages.

A representative crushed stone plant has a production rate of 454 metric tons/hr (500 tons/hr) and emits respirable particulates at a rate of 1.48 kg/hr (3.26 lb/hr) and total particulates at 12.9 kg/hr (28.4 lb/hr). The representative distance to the boundary is 410 m. The maximum severity for respirable particulates is 0.03. The population affected above severity of 0.1 is thus zero. The maximum severity for free silica particulates is 0.83 with an affected population of 172 persons for severity $\geq$0.1 and zero persons for severity $\geq$1.0. Maximum severities and mass emissions for each unit operation and pollutant are summarized in Table 1 on both a national and a representative plant basis.

Total particulate emissions from crushed stone production account for no more than 0.6% of the overall particulate emissions in any state and 0.02% of the total national particulate emissions.

By 1978, the ratio of total national particulate emissions, with the best available control technology applied, to the 1972 emissions level is expected to be 0.55.

TABLE 1. MASS EMISSIONS FROM CRUSHED STONE OPERATIONS

Unit operation	Total particulates			Respirable particulates				Free silica			
	U.S. total, metric tons/yr	Representative plant, kg/yr	% of Total emissions from all operations	U.S. total, metric tons/yr	Representative plant, kg/yr	% of Total emissions from all operations	Severity	U.S. total, metric tons/yr	Representative plant, kg/yr	% of Total emissions from all operations	Severity
Blasting	5.6	5.5	0.19	0.94	0.9	0.28	0.000081	0.015	0.02	0.27	0.0022
Wet drilling	17	17	0.59	1.7	1.7	0.50	0.00015	0.028	0.03	0.50	0.0041
Primary crushing and unloading	1,400	1,400	48	140	140	41	0.012	2.3	2.3	41	0.34
Secondary crushing and screening	66	65	2.3	36	36	11	0.0032	0.58	0.57	10	0.087
Tertiary crushing and screening	39	38	1.3	7.1	7.0	2.1	0.00061	0.11	0.11	2.0	0.017
Fines crushing and screening	9.9	9.7	0.34	1.6	1.6	0.47	0.00014	0.026	0.03	0.46	0.00038
Conveying	180	180	6.2	12	12	3.5	0.0010	0.19	0.19	3.4	0.029
Loading trucks	18	17	0.62	4.9	4.8	1.4	0.00042	0.077	0.08	1.4	0.012
Unloading trucks	14	13	0.48	5.8	5.7	1.7	0.00050	0.092	0.09	1.6	0.014
Transport on wetted roads	120	120	4.1	22	22	6.5	0.0019	0.35	0.34	6.2	0.052
Quarrying	1,100	1,100	38	112	110	32	0.0097	1.8	1.8	32	0.27
TOTAL[a]	2,900	3,000	100	340	340	100	0.03	5.6	5.6	100	0.83

(continued)

TABLE 1 (continued)

Unit operation	NO_x			CO			Fibers		
	U.S. total, metric tons/yr	Representative plant, kg/yr	Severity	U.S. total, metric tons/yr	Representative plant, kg/yr	Severity	U.S. total, 10^{12} fibers/yr	Representative plant, 10^{12} fibers/yr	Severity
Blasting	300	300	0.09	180	180	0.00017	37	0.04	[b]
Wet drilling	[c]	[c]	[c]	[c]	[c]	[c]	67	0.07	[b]
Primary crushing and unloading	[c]	[c]	[c]	[c]	[c]	[c]	5,600	5.5	0.008
Secondary crushing and screening	[c]	[c]	[c]	[c]	[c]	[c]	1,400	1.4	0.002
Tertiary crushing and screening	[c]	[c]	[c]	[c]	[c]	[c]	280	0.28	[b]
Fines crushing and screening	[c]	[c]	[c]	[c]	[c]	[c]	62	0.06	[b]
Conveying	[c]	[c]	[c]	[c]	[c]	[c]	480	0.47	[b]
Loading trucks	[c]	[c]	[c]	[c]	[c]	[c]	190	0.19	[b]
Unloading trucks	[c]	[c]	[c]	[c]	[c]	[c]	230	0.23	[b]
Transport on wetted roads	[c]	[c]	[c]	[c]	[c]	[c]	850	0.84	[b]
Quarrying	[c]	[c]	[c]	[c]	[c]	[c]	4,400	4.3	0.006
TOTAL[a]	300	300	0.09	180	180	0.00017	13,600	13	0.016

[a] Values may not equal total due to reporting in significant figures.

[b] Negligible; ≤ 0.001.

[c] No species emitted from the unit operations shown.

SECTION III

SOURCE DESCRIPTION

A. PROCESS DESCRIPTION

1. Emission Sources

The production of crushed stone refers to the conversion of stone deposits into a crushed stone form through a series of unit operations (see Figure 1). These operations are divided into two activities: mining and processing.

Mining refers to the acquisition of the stone from the stone deposits. These deposits are first loosened through wet drilling (for charging of explosives) and blasting with ANFO (ammonium nitrate and fuel oil). The explosion causes the release of gaseous and particulate pollutants. Quarrying, which releases dust to the atmosphere, involves loading the blasted material by front-end loader or shovel onto trucks or conveyors for transport to the processing plant.

Processing refers to all activities at a plant area, generally located near the quarry, where the stone is size reduced and classified through a series of screening towers and crushers. After primary crushing, material is conveyed to the top of a screening tower and dropped through the screens. Undersize stone is stockpiled, and oversize stone is crushed and conveyed to the next tower for further processing. These physical activities generate fugitive particulate emissions. Additional dust is created by gravity loading undersize material into trucks beneath the tower. These trucks unload in the stockpile area where customer trucks are filled by front-end loaders. These activities also create fugitive dust, and all occur on unpaved roads which, even wetted, also contribute to the emissions.

2. Source Definition

The definition of crushed stone used in this study is much narrower in scope than that used by the Bureau of Mines. Crushed stone is defined herein as traprock, calcareous marl, shell marble, mica schist, slate, and miscellaneous crushed stones, excluding sandstone, quartz, quartzite, granite, limestone dolomite, and dimension stones (stones $\geq$0.6 m in length and width).

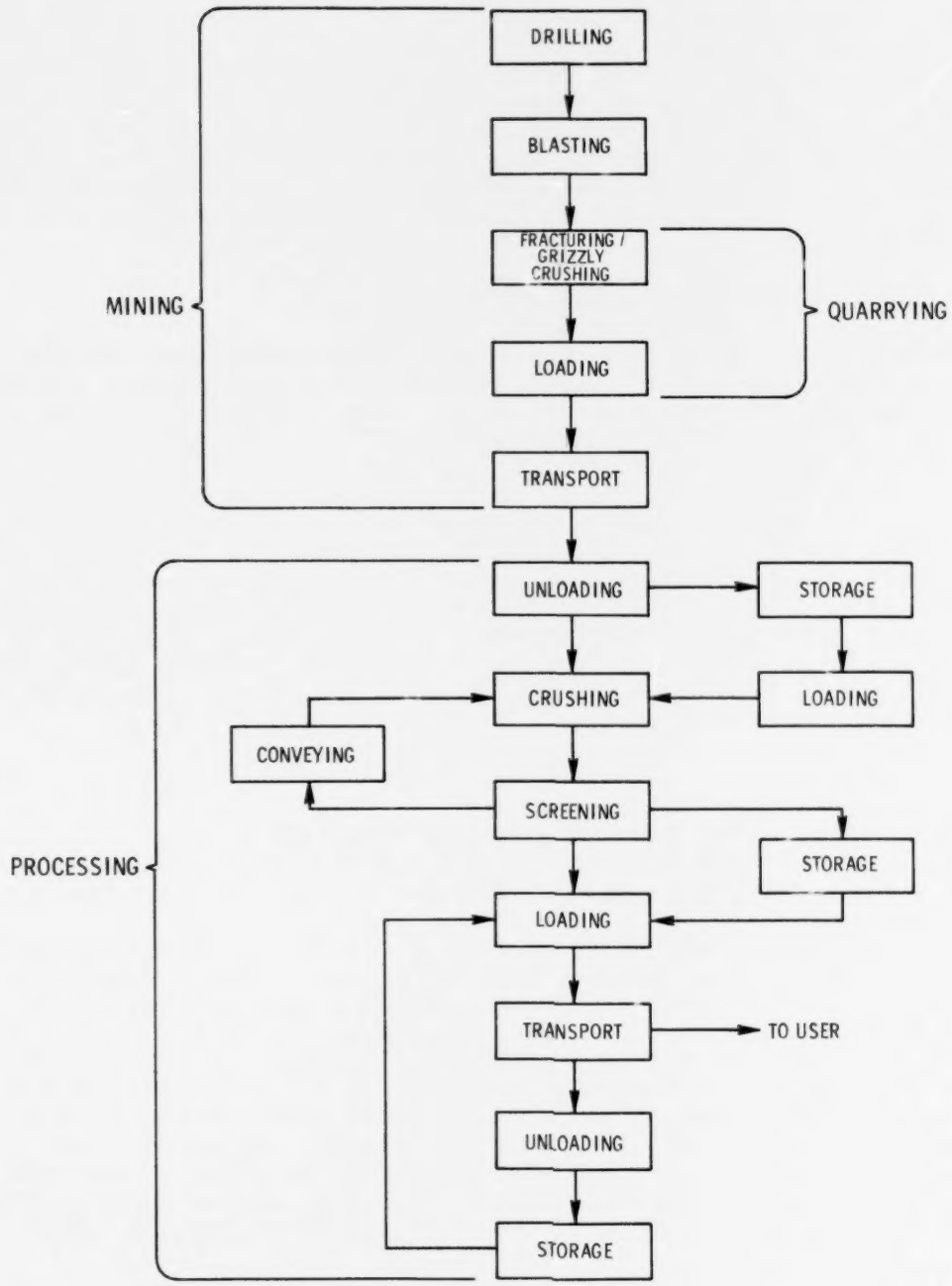

Figure 1. Production of crushed stone.

The term traprock pertains to all dark, dense, and fine-grained igneous stone deposits. Calcareous marl is a crumbly soil containing calcium carbonate. Shell marble is a coarse-grained metamorphic stone deposit produced by the action of heat and pressure on limestone and dolomite. Mica schist is derived from phyllite, a stone deposit that forms slightly more intense metamorphism than is needed to produce slate. Slate is a metamorphic rock formed by low-grade metamorphism of shale which,by itself, is a fine-grained sedimentary rock composed of clay or silt-sized particles (1).

B. FACTORS AFFECTING EMISSIONS

Calculation of the severity of the source emissions and the burden on the state and national emission levels necessitates a knowledge of the emission rate for every crushed stone facility in the U.S. The large number of facilities and the diversity of operations made it impractical to conduct emission measurements on a source-by-source basis. All production at a crushed stone facility passes through the primary crusher. Thus, a method was developed to derive an emission factor based on the grams of respirable particles emitted per metric ton of crushed stone processed using the primary crusher as a reference. The emission rate for each of the source types was then estimated as the product of this emission factor and the crushed stone production rate, expressed as metric tons per hour. The relationship can be stated as:

$$Q = E \times P \qquad (1)$$

where Q = emission rate of particulates, g/hr
E = emission factor for particulates, g/metric ton
P = production rate of crushed stone, metric tons/hr

The overall emissions from crushed stone facilities are due to drilling, blasting, loading, crushing, screening, unloading, transport, and conveying. Emissions from all of these unit operations except blasting are influenced by particle size distribution, rate of handling, moisture content of the handled material, and type of equipment used. A detailed literature survey was conducted to obtain published data on the extent to which various factors influence the overall emissions, and on the relative contributions of the unit operations to overall emissions (see Appendix A). Lack of quantitative data necessitated on-site sampling to develop an emission factor. High

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(1) Arem, J. Rocks and Minerals. Ridge Press, Inc., New York, New York, 1973. 160 pp.

volume sampling procedures (see Appendix B) were utilized to quantify the quarrying emissions, whereas portable, on-the-spot measurements were taken to identify and differentiate the emissions from the individual processing operations.

C. GEOGRAPHICAL DISTRIBUTION

In 1972 the 1,009 crushed stone facilities in the U.S. produced 1.07×10^8 metric tons (1.18×10^8 tons) of stone (personal communication with Mrs. Dunn, U.S. Department of Interior, Bureau of Mines, Washington, D.C., 27 June 1975). In Table 2 (2), New Jersey ranks first in production with 1.46×10^7 metric tons (1.61×10^7 tons), followed by Washington, Oregon, Louisiana, Connecticut, California, Massachusetts, and Pennsylvania. Together these eight states account for 66.5% of the total crushed stone production in the U.S. Traprock makes up 68% of total production (2).

Geographically, the crushed stone industry is located near the crushed stone deposits and close to the place of end use (i.e., rapidly expanding urban areas and areas where large-scale public and private works are under construction). The population densities of the states where crushed stone deposits are located are also listed in Table 2.

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(2) Drake, H. J. Stone. 1973 Bureau of Mines Minerals Yearbook, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1973. 19 pp.

TABLE 2. CRUSHED STONE PRODUCTION AND POPULATION DENSITIES BY STATE (2)

State	Production,[a] 10^3 metric tons	(10^3 tons)	Population density, persons/km^2
Alabama	1,925	(2,122)	27
Alaska	563	(621)	0.2
Arizona	1,522	(1,678)	7
Arkansas	4,911	(5,413)	15
California	7,706	(8,494)	50
Colorado	854	(941)	9
Connecticut	7,720	(8,510)	240
Georgia	871	(960)	31
Hawaii	3,426	(3,776)	49
Idaho	2,807	(3,094)	4
Indiana	249	(274)	57
Iowa	23	(25)	20
Kansas	531	(585)	11
Louisiana	8,337	(9,190)	30
Maine	798	(980)	12
Maryland	4,506	(4,967)	177
Massachusetts	6,344	(6,993)	274
Michigan	865	(954)	60
Minnesota	814	(897)	18
Mississippi	650	(717)	18
Missouri	518	(571)	27
Montana	2,089	(2,303)	2
Nevada	1,008	(1,111)	2
New Hampshire	436	(481)	32
New Jersey	14,620	(16,115)	366
New Mexico	1,152	(1,270)	3
New York	2,756	(3,038)	145
North Carolina	5,553	(6,121)	39
North Dakota	-[b]	-[b]	2
Ohio	5	(6)	102
Oklahoma	1,277	(1,408)	15
Oregon	9,734	(10,730)	9
Pennsylvania	6,232	(6,870)	103
South Carolina	2,671	(2,944)	34
South Dakota	2	(2)	2
Tennessee	175	(193)	38
Texas	5,168	(5,697)	17
Utah	823	(907)	5
Vermont	1,827	(2,014)	19
Virginia	5,368	(5,917)	46

(continued)

TABLE 2 (continued).

State	Production,[a] 10^3 metric tons	(10^3 tons)	Population density, persons/km^2
Washington	10,413	(11,478)	20
Wisconsin	1,004	(1,107)	31
Wyoming	403	(444)	1
Undistributed[c]	-21,682	(-23,900)	
Total	106,974	(117,554)	

[a] Crushed stone production per state = stone production per state less the production of other stones per state.

[b] Not available.

[c] Represents the difference between U.S. total and individual states total as reported in Reference 2; negative number represents the net difference in discrepancies found in the reference due to the method of reporting (disclosure of individual plant capacities).

SECTION IV

EMISSIONS

A. SELECTED POLLUTANTS

The major pollutant emitted from the production of crushed stone is respirable (<7-μm geometric mean diameter) particulate matter. This particulate contains free silica, the crystalline silicon dioxide which is mostly quartz, tridymite and cristobalite.

Quartz may be colorless or white, rose, violet, brown or almost any hue depending on its impurities. Tridymite forms from quartz above 870°C into white or colorless orthorhombic crystals, while cristobalite forms above 1,470°C into white cubic crystals. Quartz is usually present as a mineral constituent of rocks, while tridymite and cristobalite usually occur together as abundant high-temperature silicate minerals in the volcanic rocks of California, Colorado and Mexico (3).

A pulmonary fibrosis called silicosis develops from the prolonged inhalation of free silica dusts. The action of this dust in the lungs results in the production of a diffuse, nodular fibrosis. This condition is progressive and may continue to increase for several years after exposure is terminated. The most common symptom of uncomplicated silicosis is shortness of breath on exertion, sometimes accompanied by dry cough. Where the disease advances, the shortness of breath becomes worse and the cough more troublesome. Further progress of the disease results in marked fatigue, loss of appetite, pleuritic pain, and total incapacity to work. Extreme cases may eventually cause death due to the destruction of the lung tissues (4).

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(3) Occupational Exposure to Free Silica, Criteria for Recommended Standard. Publication No. NIOSH 75-120, U.S. Department of Health, Education and Welfare, Washington, D.C., 1974. 121 pp.

(4) Sax, N. I. Dangerous Properties of Industrial Materials, 3rd Edition. Reinhold Book Corp., New York, New York, 1968. pp. 1088-1089.

The American Conference of Governmental Industrial Hygienists (ACGIH) has suggested a TLV® (threshold limit value) for respirable particulates as shown in Equation 2:

$$TLV = \frac{10}{\% \text{ quartz} + 2} \quad (\text{for } \% \text{ quartz} \geq 1\%) \qquad (2)$$

where TLV = threshold limit value, mg/m^3
% quartz = percent of quartz in respirable dust

Respirable particulates with less than 1% quartz are termed "inert", and a TLV of 10 mg/m^3 is suggested for these (5). The criteria document on crystalline silica recently published by the National Institute of Occupational Safety and Health (NIOSH) states that occupational exposure shall be controlled so that no worker is exposed to a time-weighted average concentration of free silica greater than 50 $\mu g/m^3$ as determined by a full shift sample for up to a 10-hour workday, 40-hour workweek (3). In addition, particulate matter is one of the air quality criteria pollutants and has a 24-hour primary ambient air quality standard of 260 $\mu g/m^3$.

Fibers are also emitted from crushed stone operations. These fibers were not analyzed in detail with respect to their chemical compositions; for the purposes of source assessment they were treated as asbestos fibers. Upon prolonged inhalation, asbestos fibers have been associated with pulmonary and pleural fibrosis. The disease, asbestosis, is characterized by diffuse interstitial fibrosis in the lungs. Asbestos fibers have also been considered etiological factors in pleural calcification, bronchogenic carcinoma, and mesothelial tumors. A TLV of five fibers/ml has been recommended for asbestos fibers by the ACGIH.

Nitrous oxides and carbon monoxide are emitted from the blasting operation. These pollutants have threshold limit values of 9 mg/m^3 and 55 mg/m^3, respectively. Both of these are criteria pollutants with primary air quality standards of 100 $\mu g/m^3$ (0.05 ppm) for the annual arithmetic mean for nitrogen dioxide and 10 mg/m^3 (9 ppm) for an 8-hour average concentration for carbon monoxide.

B. CHARACTERISTICS

The mean emission factor for respirable particulate emissions from crushed stone production is 3.25 g/metric ton of crushed stone processed through the primary crusher with a standard

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(5) Documentation of Threshold Limit Value (TLV) for Substances in Workroom Air. Adopted by the American Conference of Governmental Industrial Hygienists, 1972. 97 pp.

deviation of 0.33 g/metric ton and a 95% confidence interval of 1.47 g/metric ton. The mean emission factor for total particulate emissions is 28.36 g/metric ton with a standard deviation of 3.4 g/metric ton and a 95% confidence interval of 22.2 g/metric ton. The primary crusher and quarrying operations account for 73.5% of the respirable particulate emissions and 84.2% of the total particulate emissions. Table 3 gives the emission factors for respirable and total particulate emissions from the various unit operations. The standard deviations and the 95% confidence levels are given in Table 4.

The emission factors determined for this report, based on samples taken about 35 m (~100 ft) away from the source, are about two orders of magnitude less than those reported in previous studies. Dust loading measurements taken at the inlet of a baghouse system were used to determine the previously reported emission factors. By virtue of its high airflow, a baghouse system pulls in large particles that otherwise would not be airborne at all. Thus an emission factor based on dust loading at a baghouse inlet is an inflated value. Appendix D discusses this subject in detail.

Table 5 lists the emission factors for fibers, nitrogen oxides, and carbon monoxide.

The aforementioned emission factor for total particulates was used to estimate statewide emission rates as the product of the emission factor and the crushed stone processing rate for that state. The state emission burden is thus calculated as the percent contribution of particulate emission rates for crushed stone processing in a state to the overall particulate emissions in that state. Table 6 displays the state and nationwide emission burdens (6).

It can be seen that the emissions of particulates due to crushed stone processing contribute no more than 0.6% to total particulates in any state in the U.S. and 0.02% of the nationwide emissions burden.

An analysis of the particulate emissions from crushed stone operations showed that free silica is the only hazardous component. Free silica was found to constitute 1.57% (by

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(6) 1972 National Emissions Report. U.S. Environmental Protection Agency. Publication No. EPA-450/2-74-012, Research Triangle Park, North Carolina, June 1974. 422 pp.

TABLE 3. EMISSION FACTORS FOR CRUSHED STONE OPERATIONS

Unit operation	Respirable particulates, mg/metric ton	% of Total respirable particulates from all crushed stone operations	Total particulates, mg/metric ton	% of Total particulates from all crushed s ne operations[a]	Respirable particulate, % of total particulates from unit operation
Blasting	8.8	0.27	52.2	0.18	17
Drilling (wet)	16.0	0.49	158	0.56	10
Quarrying	1,050	32.3	10,500	37.02	10
Primary crushing and unloading	1,340	41.2	13,400	47.2	10
Secondary crushing and screening	342	10.5	619	2.18	55
Tertiary crushing and screening	66.5	2.05	362	1.28	18
Fines crushing and screening	14.7	0.45	91.8	0.32	16
Conveying	113	3.48	1,730	6.10	7
Loading trucks	45.3	1.39	166	0.58	68
Unloading trucks	53.8	1.65	127	0.45	42
Transport (wet)	202	6.21	1,150	4.05	18
Total	3,250		28,400		11[b]

[a]Rounded off; does not add to 100%.

[b]Total respirable particulates as percent of total particulates from all unit operations.

TABLE 4. STANDARD DEVIATIONS AND 95% CONFIDENCE INTERVALS FOR EMISSION FACTORS

Unit operation	Respirable particulate emission factor		Total particulate emission factor		Remarks
	Standard deviation, mg/metric ton	95% Confidence interval, mg/metric ton	Standard deviation, mg/metric ton	95% Confidence interval, mg/metric ton	
Blasting	1.4	12.6	8.4	74.6	Based on coal mining studies
Drilling	8.0	12.6	79.0	125	Based on granite studies
Quarrying	210	399	2,100	3,990	Based on granite studies
Primary crushing and unloading	141	1,270	2,402	21,600	Taken as similar to secondary crusher
Secondary crushing and screening	36.1	324	111	997	Sampling results
Tertiary crushing and screening	7.0	63	65.0	583	Taken as similar to secondary crusher
Fines crushing and screening	12.0	106	73.8	662	Sampling results
Conveying	11.3	102	173	1,560	Based on granite studies
Loading trucks	24.8	222	153	1,370	Taken as similar to unloading trucks
Unloading trucks	29.4	264	117	1,050	Sampling results
Transport (wet)[a]	202	372	1,150	2,120	Based on granite studies
Overall emissions	328	1,470	3,410	22,200	

[a]Unpaved road, vehicular traffic.

TABLE 5. EMISSION FACTORS FOR FIBERS, NO_x AND CO

Pollutant	Emission factor
Fibers	128 x 10^6 fibers/metric ton
NO_x	2.85 g/metric ton
CO	1.68 g/metric ton

TABLE 6. STATE AND NATIONWIDE PARTICULATE EMISSION BURDENS FROM THE PRODUCTION OF CRUSHED STONE (6)

State	Overall particulate emissions, 10^3 metric tons/yr	Particulate emissions due to production of crushed stone, metric tons/yr	Contribution from production of crushed stone to overall state emissions, %
Alabama	1,180	55	-[a]
Alaska	13.9	16	0.12
Arizona	72.7	43	0.06
Arkansas	138	139	0.10
California	1,010	219	0.02
Colorado	201	24	0.01
Connecticut	40.1	219	0.55
Georgia	404	25	-[a]
Hawaii	61.6	97	0.16
Idaho	55.5	80	0.14
Indiana	748	7	-[a]
Iowa	216	0.7	-[a]
Kansas	348	15	-[a]
Louisiana	380	236	0.06
Maine	49.2	23	0.05
Maryland	495	128	0.03
Massachusetts	96.2	180	0.19
Michigan	706	25	-[a]
Minnesota	392	23	-[a]
Mississippi	50.6	18	0.04
Missouri	1,150	15	-[a]
Montana	872	59	-[a]
Nevada	305	29	0.01
New Hampshire	86.6	12	0.01
New Jersey	152	415	0.27
New Mexico	103	33	0.03
New York	160	78	0.05
North Carolina	481	157	0.03
North Dakota	79.0	-[b]	-[b]
Ohio	1,770	-[c]	-[a]
Oklahoma	93.6	36	0.04
Oregon	169	276	0.16
Pennsylvania	1,810	177	0.01
South Carolina	199	76	0.04
South Dakota	52.3	-[c]	-[a]
Tennessee	410	5	-[a]
Texas	549	147	0.03
Utah	71.7	23	0.03
Vermont	14.6	52	0.36
Virginia	477	152	0.03
Washington	162	295	0.18
Wisconsin	412	28	-[a]
Wyoming	75.4	11	0.01
U.S. Total	17,8 2[d]	3,649	0.02

[a] Negligible, <0.01%.

[b] Not available.

[c] Negligible, <1,0 metric ton/yr.

[d] U.S. total includes certain area sources not included in individual state inventories.

weight) of the particulates (see Table C-3, Appendix C). Other constitutents are inert and constitute 98.43% (by weight). Table 7 gives the elemental analysis of emissions from crushed stone operations.

TABLE 7. ELEMENTAL ANALYSIS OF EMISSIONS FROM CRUSHED STONE OPERATIONS

Element	Range of composition, percent by weight
Silicon	3.0 to 35.3
Calcium	2.4 to 11.8
Sodium	3.0 to 18.9
Iron	1.5 to 16.3
Aluminum	1.5 to 16.3
Magnesium	0.3 to 2.4
Titanium	0.2 to 0.7
Tin	0.01 to 0.2
Chromium	0.01 to 0.5
Lead	0.10 to 0.6
Vanadium	0.02 to 0.1
Manganese	0.02 to 0.09
Copper	0.03 to 0.12
Nickel	<0.006
Zirconium	<0.025
Silver	<0.025
Zinc	<0.5
Molybdenum	<0.24
Boron	<0.12

C. DEFINITION OF THE REPRESENTATIVE SOURCE

A traprock producing facility was chosen as representative of the crushed stone industry for two reasons:

- Traprock constitutes the majority (68%) of the crushed stone output; and
- It is a dark igneous rock which may contain fibrous material (such as asbestos); thus, it would show the worst case of hazard potential for the crushed stone industry from this material viewpoint.

Emissions due to crushed stone processing can be expressed as stated earlier in Equation 1. The representative source is defined as one that has the mean emission parameters; i.e., mean emission factor and mean production rate. Consultations with industry experts showed that crushed stone plants have production rates of from 90 metric tons/hr (~100 tons/hr) to

1,080 metric tons/hr (1,190 tons/hr) with a mean of 454 metric tons/hr (~500 tons/hr).

The mean emission factor was determined by sampling two traprock plants whose production rates are similar to that of the representative plant (Appendix C). Thus the representative source has an emission rate of 1.5 kg/hr for respirable particulates.

The sampled plants had an average area of 0.53 km^2. The representative distance to plant boundaries was taken as the radius of a circle whose area is equal to the area of the plant. For an area of 0.53 km^2, this is equal to 410 meters. The representative population density was taken as the mean population density of the eight leading crushed stone producing states (New Jersey, Washington, Oregon, Louisiana, Connecticut, California, Massachusetts, and Pennsylvania) which account for 66.5% of crushed stone output. The representative population density was determined to be 137 persons/km^2.

D. SOURCE SEVERITY

The maximum source severity due to respirable particulate emissions from the representative crushed stone facility is 0.03. (Severity calculations are given in Appendix E.) The affected population is zero.

The maximum source severity due to free silica emissions is 0.83. Emissions of free silica particles affect a population of 172 persons at $\geq$410 meters for a severity greater than 0.1 and zero persons for a severity $\geq$1.0.

The maximum source severity due to fiber emissions is 0.02 and the affected population is zero.

SECTION V

CONTROL TECHNOLOGY

A. STATE OF THE ART

The unpaved roads at crushed stone plants are frequently sprayed with water or oil to control air emissions. This is done in compliance with a Department of Interior regulation designed to keep dust levels in the plant below the threshold limit values prescribed by the American Conference of Governmental Industrial Hygienists. Thus the unpaved road emissions constitute less than 6% of the overall plant emissions. If the unpaved road emissions were uncontrolled, the overall plant emissions would be about seven times the controlled value and unpaved road contributions would constitute more than 85% of total plant emissions.

Control techniques are not widely applied to emissions from other sources such as crushing, screening, conveying, and stockpiling. Some plants use a baghouse and/or wet suppression systems to control dust emissions. Wet drilling is also employed by some to reduce drilling emissions.

Since the amount of dust generated from the various operations is dependent on the dryness of the material, any addition of water is helpful in reducing emissions. Natural occurrences, such as rain or snow, and in-process washing and spraying thus control emissions.

B. FUTURE CONSIDERATIONS

A number of control techniques that may find application in controlling emissions from crushed stone operations are discussed below.

Dust emissions from dry percussion drilling operations can be controlled by adding water, or water mixed with a surfactant, into the air used for flushing the drill cuttings from the hole. Dilution ratios range from 800 to 3,000 parts of water

to 1 part of surfactant. The proper amount of solution, about 0.026 m^3/hr[a] (7 gal/hr) for an 89-mm (3 1/2-in.) diameter hole, causes the drill cutting to be blown from the hole as damp, dust-free pellets (7).

Water filled plastic bags with or without solid stemming material (clay) are used for stemming dust emissions from blast holes. This method reduces dust concentrations by 20% to 80% and explosive consumption by about 10% (8). Pastes with a cellulose or bentonite base can be used instead of liquids if the pastes have "thixotropic" properties; i.e., they are gelatinous in repose, but become liquid when vibrated.

Release of carbon monoxide, nitric oxide, and other gases such as aldehydes and hydrogen can be curtailed by having a dry blast hole and by carrying out the detonation properly to prevent incomplete combustion.

Blasted stone is loaded into trucks by front-end loaders, creating dust emissions. Wetting of the broken stone with water or water mixed with a surfactant will alleviate the dust emissions. Emissions due to wind erosion during transport can be reduced by covering the truck bed with a tarpaulin or wetting the surface of theload with water or water mixed with chemicals.

A number of methods are available for more effectively controlling emissions from unpaved roads. Water application is effective, but about 5% to 8% moisture (by weight) must be achieved to suppress the dust emissions (9). Additives such as calcium chloride can be used to reduce the surface tension of water so that the dust can be wetted with less water. Calcium chloride can be applied at a cost of approximately $\$0.15/m^2$ treated per year (7). A major problem here is the corrosion of vehicle bodies and leaching by rain water or melting snow. More frequent applications may be necessary during summer months.

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[a] 1 m^3 = 1 $meter^3$ = 1,000 liters.

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(7) Jones, H. R. Fine Dust and Particulates Removal. Noyes Data Corporation, Park Ridge, Illinois, 1972. 307 pp.

(8) Grossmueck, G. Dust Control in Open Pit Mining and Quarrying. Air Engineering, 10(25):21, July 1968.

(9) Dust Suppression. Rock Products, 75:137, May 1972.

Another effective dust control method for unpaved roads is to mix stabilization chemicals into the road surface to a depth of about 20 mm to 50 mm (10). One cement company sprays a solution of 4 parts of water and 1 part of a special emulsion agent[a] at the rate of approximately 0.009 m^3/m^2 (2 gal/yd^2) of road surface. Certain pretreatment measures such as working the road surface into a stiff mud are necessary to prevent the binder in this emulsion agent from sticking to the vehicles. Periodic maintenance such as a 1:7 emulsion agent/water solution spray keeps the emulsion agent binder active. This dust control program was found to give 3 years of service at a total cost of $\$0.12/m^2$.

Mixing cutback asphalt into the road surface to a depth of 50 mm to 80 mm has been investigated in some counties in Iowa (11). Such surface treatment reduces dust emissions, but it requires periodic maintenance such as patching of the potholes.

Treating the road surface with oil once a month is another efficient way to control unpaved road dust emissions. The cost for such applications is estimated to be $\$0.10/m^2$ treated per year (12). However, a study conducted by the Edison Water Quality Research Laboratory in New Jersey shows that 70% to 75% of the oil applied moves from the surface of the road by dust transport and runoff, and thus ecological damage may be caused by the oil or its heavy metal constituents such as lead (12). Furthermore, surface oiling requires regular maintenance, as roads treated in this way develop potholes.

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[a]Coheren, Golden Bears Division, Witco Chemicals Company.

(10) Significant Operating Benefits Reported from Cement Quarry Dust Control Programs. Pit and Quarry, 63(7):116, January 1971.

(11) Hoover, J. M. Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets, Final Report. Publication No. ER-1, Project 856-S, Iowa State University, Engineering Research Institute, Ames, Iowa, July 1973. 364 pp.

(12) Runoff of Oils from Rural Roads Treated to Suppress Dust. Report No. R2-72-054, Edison Water Quality Research Laboratory, Edison, New Jersey, October 1972. 29 pp.

Lignin sulfonates, by-products from paper manufacture, are also used to control dust emissions. One of the commercially available lignin sulfonates[a] was tested on a farm access road at Arizona State University (13). The method proved quite successful, giving effective dust suppression for 5 years at a cost of $\$0.47/m^2$ ($\$0.10/m^2$-year).

The best method for controlling dusts is to pave the road surface, but this is impractical due to the high cost involved and the temporary nature of crushed stone plants.

The simplest and least expensive means of controlling dust from crushing, screening, conveying, and stockpiling is through the use of wetting agents and sprays at critical points. Efficiencies up to 95% can be achieved in these systems. A crushed rock production plant uses a dust suppression system and a chemical wetting agent.[b] Approximately 0.004 m^3 of concentrated wetting agent is diluted 1,000 times by volume with water using an automatic proportioner. The solution is sprayed at the top and bottom of cone crushers at the rate of 0.0042 m^3 of solution per metric ton of material being crushed. This system also helps in reducing dust emissions at transfer points, screening operations, storage bins, and stockpiling operations (14). Such a system has many cost-saving advantages. It requires no ducts, hooding, or other enclosures for crushers, screens, or conveyor transfers. Since the equipment is in the open the operators can see the entire material flow. The dust is not collected so there is no solid waste disposal or water pollution problem.

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[a] Orzan A, Crown Zellerbach Corporation.

[b] Chem-Jet, Johnson-March Corporation.

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(13) Bub, R. E. Air Pollution Alleviation by Suppression of Road Dust. M.S.E. thesis, Arizona State University, Tempe, Arizona, June 1968. 45 pp.

(14) Harger, H. L. Methods Used by Transit Mix Operators to Meet Air Pollution Control District Requirements. National Sand and Gravel Association and Ready Mixed Concrete Association, April 1971. 22 pp.

In a crushed stone plant, a baghouse is used to control dust emissions from cone crushers, scalping screens, twin sizing screens, and at the shuttle and transfer conveyors at an efficiency of 99.8%. Anywhere from 2,722 kg to 5,443 kg of dust is collected in a 10-hour day from a 182-metric ton/hr plant (15). A baghouse does not control dust in stockpile areas unless these areas are totally enclosed. Further, the dust collected in the baghouse presents a solid waste problem. The alternative disposal methods are to put the dust into settling basins or to incorporate it into a useful product which may be sold. Depending on the type of material and the local market conditions, such uses may include manufactured sand, underslab fill, and asphalt filler (16).

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(15) Trauffer, W. E. Main's New Dust-Free Crushed Stone Plant. Pit and Quarry, 63(2):96, August 1970.

(16) Ozol, M. A., S. R. Locke, et al. Study to Determine the Feasibility of an Experiment to Transfer Technology to the Crushed Stone Industry. National Science Foundation, Contract NSF-0826, Martin Marietta Laboratories, Baltimore, Maryland, June 1974. 106 pp.

SECTION VI

GROWTH AND NATURE OF THE INDUSTRY

A. PRESENT TECHNOLOGY

Present technological improvements in the crushed stone industry include the use of larger and more efficient crushing and screening units. Primary crushing is often done near the pit, usually by jaw or gyratory crushers. Other crushing is accomplished using cone or gyratory crushers. Horizontal screens are generally used for size classification. The crushed and classified stone is stored in open areas. In the larger and more efficient plant, stone is drawn out through tunnels under the storage piles and equipment is designed to blend any desired mixture of sizes.

B. EMERGING TECHNOLOGY

No emerging technology of specific importance to air pollution control in the crushed stone industry was found in this study.

C. PRODUCTION TRENDS

Production of crushed stone from 1945 to 1968 increased at a rate of 2.7% per year. Contingency forecasts for the year 2000 predict a mean growth rate of 4.25% per year. These growth rates are reflected in Figures 2 and 3, respectively.

Production of crushed stone is tied very closely to activity in the stone consuming industries. Since the construction industry consumes more than 81% of the crushed stone output, the production of crushed stone is associated chiefly with the needs of this industry. By 1978 the total production of crushed stone is forecast to be 1.37×10^{8} metric tons.

With all available controls applied, total particulate emissions in 1978 would be 1,679 metric tons (Appendix E). The 1972 level of emissions was 3,034 metric tons, based on uncontrolled crushed stone facilities. The growth factor or ratio of 1978 to 1972 emissions is thus 0.55.

Transportation costs have a large effect on the production trends of the crushed stone industry, since they constitute a major part of the delivered cost of crushed stone. In many

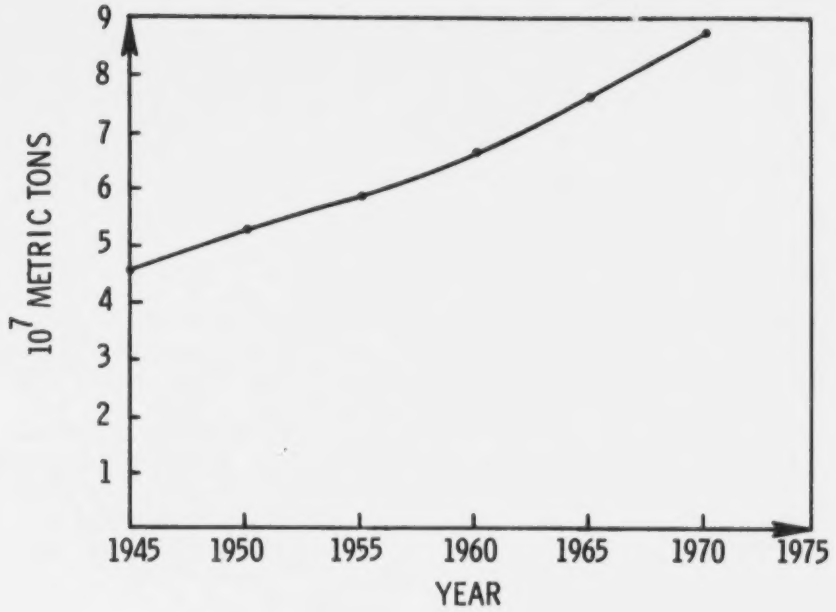

Figure 2. Trends in the production of crushed stone in the United States.

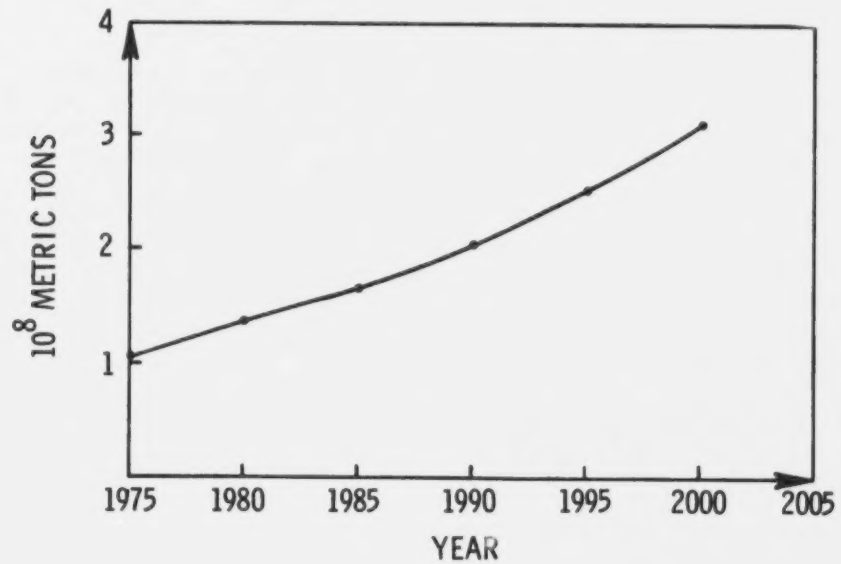

Figure 3. Mean trend projection for crushed stone.

cases, the processing plants are therefore located near the point of use. However, local zoning and environmental regulations, and depletion of urban deposits, may necessitate the location of future processing plants away from the points of use. This should increase the use of rail and barge transport in order to hold down shipping costs. Truck haulage will still remain important, especially for local delivery of crushed stone. If rail and water systems are used for long hauls to central distribution points, this may finally result in an increase in the delivered price of crushed stone.

REFERENCES

1. Arem, J. Rocks and Minerals. Ridge Press, Inc., New York, New York, 1973. 160 pp.

2. Drake, H. J. Stone. 1973 Bureau of Mines Minerals Yearbook, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1973. 19 pp.

3. Occupational Exposure to Free Silica, Criteria for Recommended Standard. Publication No. NIOSH 75-120, U.S. Department of Health, Education and Welfare, Washington, D.C., 1974. 121 pp.

4. Sax, N. I. Dangerous Properties of Industrial Materials, 3rd Edition. Reinhold Book Corp., New York, New York, 1968. pp. 1088-1089.

5. Documentation of Threshold Limit Value (TLV) for Substances in Workroom Air. Adopted by the American Conference of Governmental Industrial Hygienists, 1972. 97 pp.

6. 1972 National Emissions Report. U.S. Environmental Protection Agency. Publication No. EPA-450/2-74-012, Research Triangle Park, North Carolina, June 1974. 422 pp.

7. Jones, H. R. Fine Dust and Particulates Removal. Noyes Data Corporation, Park Ridge, Illinois, 1972. 307 pp.

8. Grossmueck, G. Dust Control in Open Pit Mining and Quarrying. Air Engineering, 10(25):21, July 1968.

9. Dust Suppression. Rock Products, 75:137, May 1972.

10. Significant Operating Benefits Reported from Cement Quarry Dust Control Programs. Pit and Quarry, 63(7):116, January 1971.

11. Hoover, J. M. Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets, Final Report. Publication No. ER-1, Project 856-S, Iowa State University, Engineering Research Institute, Ames, Iowa, July 1973. 364 pp.

12. Runoff of Oils from Rural Roads Treated to Suppress Dust. Report No. R2-72-054, Edison Water Quality Research Laboratory, Edison, New Jersey, October 1972. 29 pp.

13. Bub, R. E. Air Pollution Alleviation by Suppression of Road Dust. M.S.E. thesis, Arizona State University, Tempe, Arizona, June 1968. 45 pp.

14. Harger, H. L. Methods Used by Transit Mix Operators to Meet Air Pollution Control District Requirements. National Sand and Gravel Association and Ready Mixed Concrete Association, April 1971. 22 pp.

15. Trauffer, W. E. Main's New Dust-Free Crushed Stone Plant. Pit and Quarry, 63(2):96, August 1970.

16. Ozol, M. A., S. R. Locke, et al. Study to Determine the Feasibility of an Experiment to Transfer Technology to the Crushed Stone Industry. National Science Foundation, Contract NSF-0826, Martin Marietta Laboratories, Baltimore, Maryland, June 1974. 106 pp.

17. Chaiken, R. F. Ammonium Nitrate-Fuel Oil Mixtures. In: Toxic Fumes from Explosives. Publication No. PB 233 496, Bureau of Mines, Washington, D.C., May 1974. 24 pp.

18. Blackwood, T. R., and P. K. Chalekode. Source Assessment Document: Transport of Sand and Gravel. Contract 68-02-1320, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. (Preliminary document submitted to the EPA by Monsanto Research Corporation, December 1974.) 87 pp.

19. Cheng, Lung. Formation of Airborne-Respirable Dust at Belt Conveyor Transfer Points. American Industrial Hygiene Association Journal, 34:540-546, December 1973.

20. Cowherd, Chatten. Development of Emission Factor for Fugitive Dust Sources. Publication 1152, Midwest Research Institute, Kansas City, Kansas. Presented at APCA meeting, Denver, Colorado, June 1974. 175 pp.

21. Andresen, W. V. Industrial Hygiene Design in Raw Materials Handling Systems. American Industrial Hygiene Association Journal, 23(6):509-513, November-December 1962.

22. Blackwood, T. R., T. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Contract 68-02-1320, Task 6, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1975. p. 34.

23. Turner, D. B. Workbook of Atmospheric Dispersion Estimates, 1970 Revision. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

24. Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 6:859-863, March 1972.

25. Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

26. Aerosol Technology Committee. Guide for Respirable Mass Sampling. American Industrial Hygiene Association Journal, 31:133, January-February 1970.

27. Larsen, D. M., L. J. Von Doenhoff, and J. V. Crable. The Quantitative Determination of Quartz in Coal Dust by Infrared Spectroscopy. American Industrial Hygiene Association Journal, 33:367-372, June 1972.

28. Freedman, R. W., S. Z. Toma and H. W. Lang. On-Filter Analysis of Quartz in Respirable Coal Dust by Infrared Absorption and X-Ray Diffraction. American Industrial Hygiene Association Journal, 35:411-418, July 1974.

29. Durken, T. M. Determination of Free Silica in Industrial Dust. Journal of Industrial Hygiene and Toxicology, 28:217, February 1946.

30. Edwards, G. H. Comparison of X-Ray Diffraction, Chemical (Phosphoric Acid), and Dispersion Staining Methods for the Determination of Quartz. American Industrial Hygiene Association Journal, 26:532, September-October 1965.

31. Freedman, R. W. Recent Advances in the Analysis of Respirable Coal Dust for Free Silica, Trace Elements, and Organic Constituents. Annals of the New York Academy of Sciences, 200:7-16, December 1972.

32. Cares, J. W., A. S. Goldin, J. J. Lynch, and W. A. Burgess. The Determination of Quartz in Airborne Respirable Granite Dust by Infrared Spectrophotometry. American Industrial Hygiene Association Journal, 34:298-305, July 1973.

33. Gifford, F. A., Jr. Chapter 3 - An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Slade, D. A. (ed.). Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. p. 445.

34. Compilation of Air Pollutant Emission Factors. Office of Air Programs Publication No. AP-42, U.S. Environmental Protection Agency. Research Triangle Park, North Carolina, February 1972.

35. Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. (Final document submitted to the EPA by Monsanto Research Corporation, October 1975.) 109 pp.

APPENDIX A

LITERATURE SURVEY

A study was made to predict and analyze the parameters that affect dust emissions from the six handling operations in crushed stone processing:

- Drilling and blasting operations
- Transport operations
- Conveying operations
- Unloading operations
- Loading operations
- Crushing/grinding/sizing operations

Parameters analyzed fell into two major classifications: those dependent on the material, and those dependent on the operation. As could be expected, parameters dependent on the operation are as varied as the operations themselves. Material-dependent parameters, however, are generally the same for all operations. These are moisture content, density, and "dustiness index," which will be defined as the mass of respirable dust adhering to one pound of material.

The "dustiness index" is used to determine differences in emissions from different materials undergoing the same operation. Density, on the other hand, delineates differences in particle size distribution between different samples of the same material.

1. DRILLING AND BLASTING OPERATIONS

The following factors influence the dust emissions from drilling operations:

(1) Number of bits
(2) Sharpness of the bits
(3) Speed of the bits
(4) Depth of bit penetration
(5) Experience of the machine operator

The literature search did not yield any quantitative data or indicate a relationship between the emission factor and the aforementioned factors. A qualitative relationship might possibly resemble:

$$E_d = \frac{(1)(3)}{(2)(4)(5)} \qquad \text{(A-1)}$$

where the numbers in parentheses represent functions of the respective variables shown above.

Of all the unit operations, blasting has been studied least from the point of view of dust emissions. The literature search yielded a potential list of factors influencing emissions: frequency of blasting; bulk moisture content of the rock; particle size distribution; type and amount of explosive; and hole size.

Some studies have been conducted on the magnitude of gaseous emissions of NO_x and CO from blasting. Stoichiometric ratios of ammonium nitrate-fuel oil (ANFO) mixtures (94.5% to 5.5%) should result in no emissions of NO_x and CO. Theoretically, more fuel oil results in no NO_x and more CO than CO_2, and less fuel oil results in no CO and more NO_x than N_2. Experimental investigations by the Bureau of Mines (17) show that 4% fuel oil results in 1.3 m^3 (at standard conditions) of NO_x per kg of ANFO (0.10 std ft^3 of NO_x per lb of ANFO) and 1.3 m^3 of CO per kg of ANFO (0.10 std ft^3 of CO per lb of ANFO), while 6% fuel oil results in 0.32 m^3 of NO_x per kg of ANFO (0.025 std ft^3 of NO_x per lb of ANFO) and 1.8 m^3 of CO per kg of ANFO (0.14 std ft^3 of CO per lb of ANFO). The maximum emission factor figures have been used for the severities calculated in Appendix E.

2. TRANSPORT OPERATIONS

Transport operations have been discussed in detail in a separate document (18).

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(17) Chaiken, R. F. Ammonium Nitrate-Fuel Oil Mixtures. In: Toxic Fumes from Explosives. Publication No. PB 233 496, Bureau of Mines, Washington, D.C., May 1974. 24 pp.

(18) Blackwood, T. R., and P. K. Chalekode. Source Assessment Document: Transport of Sand and Gravel. Contract 68-02-1320, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. (Preliminary document submitted to the EPA by Monsanto Research Corporation, December 1974.) 87 pp.

3. CONVEYING OPERATIONS

Dust emissions from conveying operations come from windblown dust during open conveying and conveyor discharge.

Emissions from conveyor discharge and parameters affecting these emissions were evaluated by Cheng (19). The material tested was freshly mined coal, cut during a dry operation and placed in plastic bags to maintain its natural surface moisture of about 0.8% as measured by a Soiltest Speedy Moisture Tester. Cheng found the following relationship:

$$R = 8.50 \times 10^{-5} \left(\frac{A' \bar{\rho}_c \sqrt{2gH}}{2m' \; b \; U_b} \right)^{1.16} \qquad \text{(A-2)}$$

where R = specific formation of airborne respirable dust, g

A' = cross-sectional area of the falling granules, cm^2

$\bar{\rho}_c$ = material density of the coal, g/cm^3

g = gravitational acceleration = 980 cm/s^2

H = height of fall, cm

m' = belt load, g/cm^2

b = width of the conveyor belt, cm

U_b = linear speed of the conveyor belt, cm/s

Cheng concluded the following:

- About 10% of the adhering respirable dust becomes airborne by the impact of dropping.
- Reduction of the height of material fall reduces the formation of airborne respirable dust.
- For heavy belt loads (bed thickness >> mean lump size), an increase in the thickness of the coal bed reduces the specific formation of airborne respirable dust.

4. UNLOADING OPERATIONS

Emissions from unloading operations result from dropping materials from conveying machinery onto storage piles. A Midwest

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(19) Cheng, Lung. Formation of Airborne-Respirable Dust at Belt Conveyor Transfer Points. American Industrial Association Journal, 34:540-546, December 1973.

Research Institute study (20) found an emission factor, E_u, for unloading operations, based on kilograms of suspended dust particles less than 30 μm in diameter per metric ton of aggregate unloaded, to be represented by the relationship:

$$E_u = \frac{0.02 \text{ kg of particulate}}{\text{metric ton of aggregate}} \qquad \text{(A-3)}$$

This emission factor was based on high volume sampling at a sand and gravel plant in the Cincinnati area. The emission factor, E_u, was believed to be dependent on the surface moisture of the material, estimated by the Precipitation-Evaporation (P-E) Index.

For an analysis of other factors affecting emissions from unloading operations, see Section 3 above, "Conveying Operations." Although the relationships derived for emissions from conveyor discharge are based on the conveying of coal, only a correction factor for the relative dustiness of the material handled need be applied to make the equation applicable to all conveying and unloading operations.

5. LOADING OPERATIONS

Emissions from loading operations occur in the transfer of material from storage to transporting vehicles. For aggregates, this transfer is accomplished by power shovels that scoop material from open storage piles and dump it into transporting vehicles, usually trucks. Dust arises from the scooping and the dropping processes.

Emissions from dropping are determined by many of the same parameters that determine dust formation from conveyor discharge, although there are definite dissimilarities in mode of discharge between conveyor belts and power shovels. Dust emissions should be determined by:

(1) Height of material fall

(2) Quantity of material dumped

(3) Density of material

(4) Rate at which material is dumped

(5) Moisture content of material

(6) "Dustiness index" of material

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(20) Cowherd, Chatten. Development of Emission Factor for Fugitive Dust Sources. Publication 1152, Midwest Research Institute, Kansas City, Kansas. Presented at APCA meeting, Denver, Colorado, June 1974. 175 pp.

An equation determining the amount of respirable dust, R_d, formed by power shovel discharge, based on an equation for conveyor discharge, should be of the form:

$$R_d \propto \frac{(1)(3)(6)}{(2)(4)(5)} \qquad \text{(A-4)}$$

Each number in parentheses in Equation A-4 represents a function of its respective parameter, as listed above.

Dust emissions from scooping operations are more difficult to define, since no information even remotely relevant was available. However, the following factors are believed to be influential in determining emissions from this source:

(7) Density of material

(8) Moisture content of material

(9) "Dustiness index" of material

(10) Degree of storage pile disturbance rendered by the scooping machinery

Although there is no basis for determining a relationship between these variables and respirable dust formation, R_d, a qualitative relationship might possibly resemble:

$$R_d \propto \frac{(7)(9)(10)}{(8)} \qquad \text{(A-5)}$$

where each number in parentheses represents a function of the respective variable shown above.

Although not applicable to the determination of the respirable dust formation (R_d), a Midwest Research Institute study (20) found an emission factor, E_1, expressed as kilograms of dust less than 30 μm in diameter emitted per metric ton of material loaded, for loading crushed limestone at an asphalt plant in Kansas City to be:

E_1 = 0.025 kg of dust/metric ton of material loaded (A-6)

The emission factor, E_1, was believed to vary inversely with the square of the P-E Index of the area considered.

6. CRUSHING/GRINDING/SIZING OPERATIONS

Emissions from crushing, grinding, and sizing operations result from respirable dust formed during size reduction and crusher or screen discharge.

The factors affecting discharge emissions are the same as those for conveyor and power shovel discharge (see Section 3, "Conveying Operations," and Section 5, "Loading Operations," above).

Dust emissions from size reduction are judged to be influenced by:

(1) "Dustiness index" of material

(2) Moisture content of material

(3) Degree of particle-size reduction

(4) Rate of material flow through size reducer

A qualitative expression for respirable dust formation, R_d, is believed to be:

$$R_d \propto \frac{(1)(3)}{(2)(4)} \qquad \text{(A-7)}$$

where each number in parentheses is some function of the respective parameter listed above.

If atmospheric dispersion of the respirable dust formed is to occur, an induced airflow (Q) must be present. For most crushers, which operate at a relatively low speed, airflow is induced only during discharge. (See Section 3 in this Appendix for a quantitative evaluation of airflow induced by discharge.)

High speed pulverizers create airflow during size reduction as well as discharge. Airflow induced by high speed size reduction has been found to be inversely proportional to the rate of material flow through the size reducer (21).

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(21) Andresen, W. V. Industrial Hygiene Design in Raw Materials Handling Systems. American Industrial Hygiene Association Journal, 23(6):509-513, November-December 1962.

APPENDIX B

SAMPLING EQUIPMENT, PROCEDURES, AND ANALYSIS

Since analytical expressions for emission rates could not be derived, two types of monitors were used to sample the air pollution emissions from crushed stone operations. High volume samplers were used to sample the quarrying activities. A portable dust monitor was used to sample the various unit operations of the processing plant. This appendix describes the high volume sampling methods and equipment used, the portable dust monitoring apparatus and procedure employed, and the equipment and methods used to analyze the emissions that were sampled.

1. HIGH VOLUME SAMPLING METHODS AND EQUIPMENT

High volume samplers[a] were positioned around the quarrying source as shown in Figure B-1. Some rules used for positioning the high volume samplers are listed in Table B-1 and additional guidelines used for such sampling are presented in Table B-2. Figure B-2 gives the flow chart for determination of atmospheric stability class (22). The positions of samplers S_0, S_1, S_2, S_3, and S_4 are recorded on the form shown in Figure B-3. Atmospheric stability and barometric pressure are also recorded on this form.

Quarrying samples were taken on a day when there were no processing activities to create background interference. High volume samplers were used because the quarrying operations were located in a pit where emissions were not readily entrained in the wind. In addition, the quarrying operation is an area source of pollutants. Thus on-the-spot measurement of point sources was not possible.

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[a]General Metal Works, Inc., Cleveland, Ohio.

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(22) Blackwood, T. R., T. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Contract 68-02-1320, Task 6, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1975. p. 34.

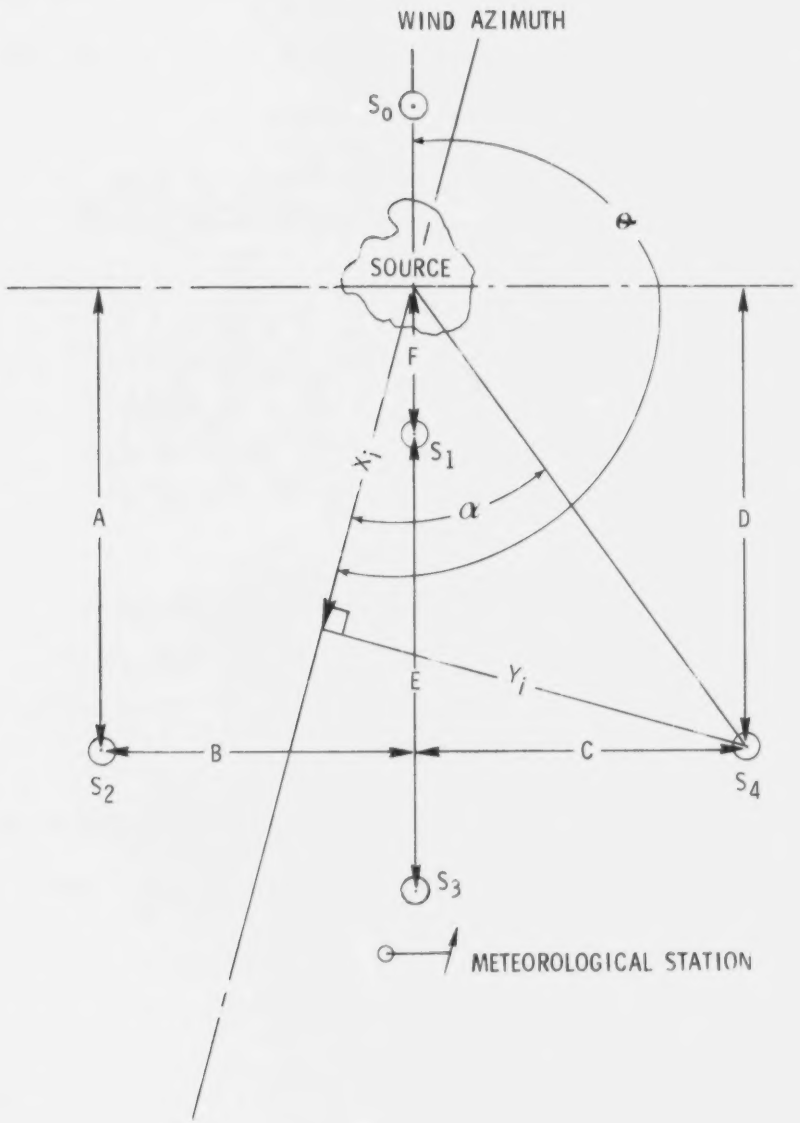


Figure B-1. High volume sampling arrangement of high volume samplers labeled S_0, S_1, S_2, S_3, and S_4.

TABLE B-1. PLACEMENT OF SAMPLES DOWNWIND OF OBSTRUCTIONS

1. Both the open source height and the obstructions must meet the required minimum distance criteria.
2. Stability class is determined from cloud cover, wind speed, and time of day (see Figure B-2).
3. The height of obstruction or source equals H.

Stability class	Minimum distance downwind from obstruction peak
A	5H
B	7H
C	10H
D	17H
E	25H[a]
Other classes	Cannot be done

[a]Requires an additional sampler at least 15H downwind for backup.

TABLE B-2. OPEN SOURCES SAMPLING GUIDELINES

1. Determine predicted wind direction and speed from:
   a. U.S. Weather Bureau and/or
   b. Field estimate
2. Determine atmospheric stability class expected - see table on worksheet (Figure B-2).
3. Locate positions of samplers around source. Use guidelines for downwind distance (Table B-1).
4. Place upwind sampler (background) and start sampling.
5. Place wind instrument and downwind samplers for source monitoring.
6. Monitor wind direction and speed every 15 minutes and stability class every 2-3 hours; note time sampler flow rates were checked at first 1/2 hour and then every 1-1/2 hours. If wind direction is off centerline by more than 0.78 rad (45°) in two consecutive readings, stop samplers until direction returns within 0.78 rad (45°) for 15 minutes.
7. Complete sampling in minimum sampling time determined by project leader.

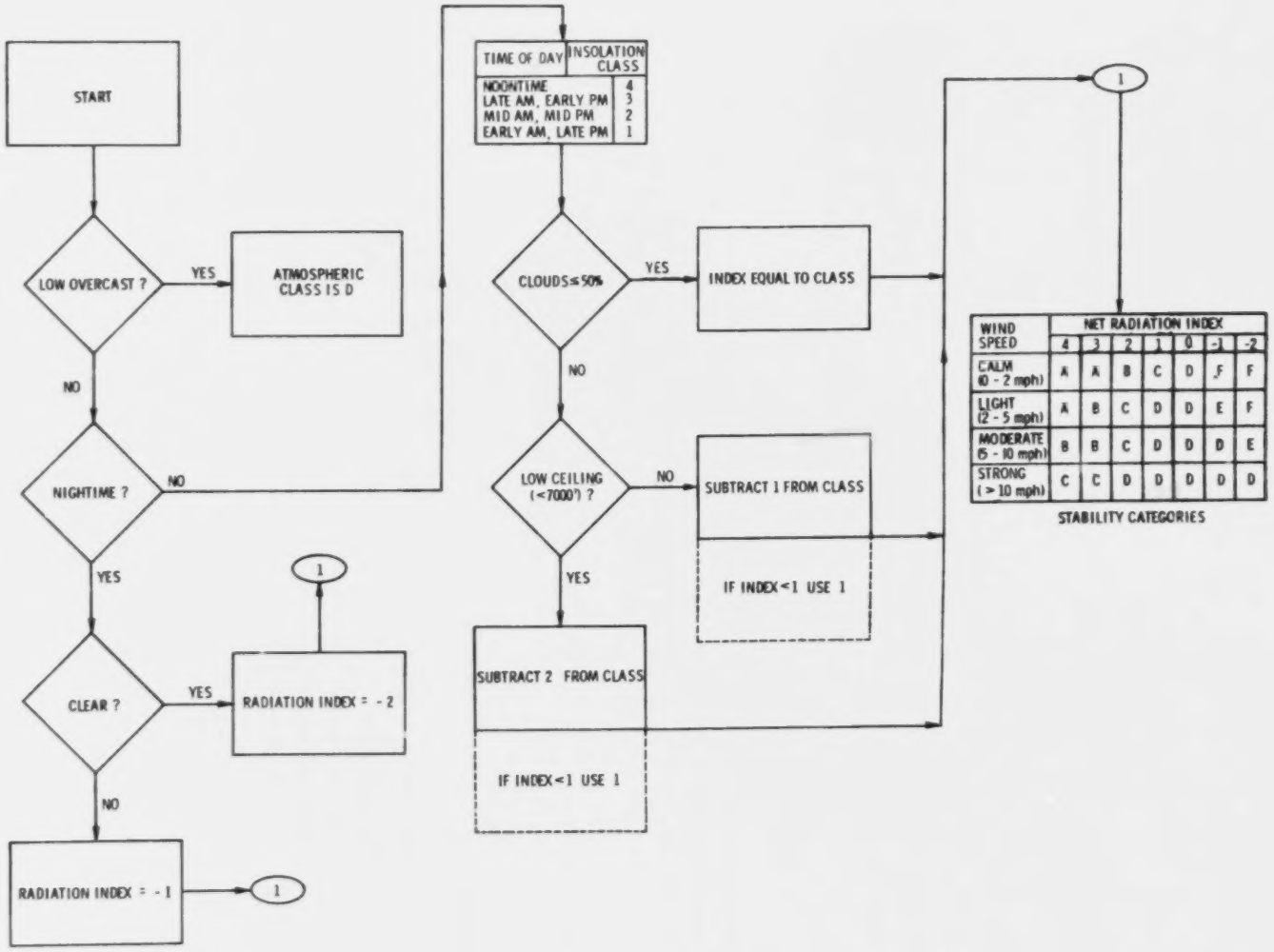
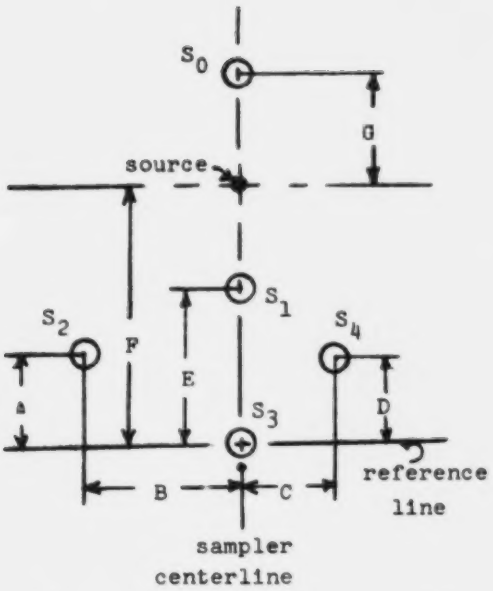


Figure B-2. Flow chart of atmospheric stability class determination (22).

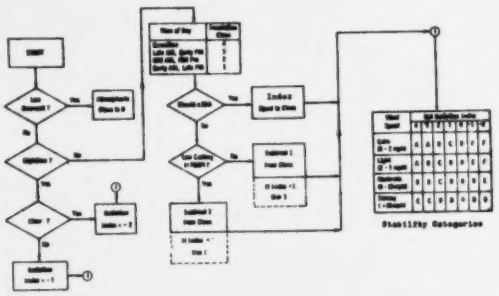


Run No. _____
DATE _____

actual barometric pressure _____ "Hg

dry bulb	_____ °F	_____ °F
wet bulb	_____ °F	_____ °F

ATMOSPHERIC STABILITY DETERMINATION



A	_____ ft. (measured)		
B	_____ ft. "		
C	_____ ft. "		
D	_____ ft. "		
E	_____ ft. "		
F	_____ ft. (estimated)		
G	_____ ft. "		

TIME	_____	STABILITY	_____
"	_____	"	_____
"	_____	"	_____
"	_____	"	_____

COMMENTS:

Sampler	Filter No.
S_0	_____
S_1	_____
S_2	_____
S_3	_____
S_4	_____

Brinks sampler located next to S_1
wind instrument is behind S_3
obtain sample of source before signing sheet

Sampling crew _____
_____
_____

Figure B-3. Fugitive dust sampling worksheet.

The arrangement in Figure B-1 permitted correlation with horizontal dispersion, and sampler S_3 illustrated downwind power law decay. For this arrangement, the origin was defined as the source with all remaining points in the usual Cartesian coordinate system. The angle of mean wind direction was θ. The downwind distance, X_i, of any point S_i to the wind direction centerline was computed in the following manner:

$$m_1 = \tan \theta \qquad \text{(B-1)}$$

and for point S_i with Cartesian coordinates x_i, y_i (e.g., for point S_4, $x_i = D$, $y_i = C$)

$$m_2 = \frac{y_i}{x_i} \qquad \text{(B-2)}$$

the angle α was found from:

$$\alpha = \arctan \frac{m_1 - m_2}{1 + m_1 \cdot m_2} \qquad \text{(B-3)}$$

the lateral distance Y_i is:

$$Y_i = (\sin \alpha) \sqrt{x_i^2 + y_i^2} \qquad \text{(B-4)}$$

and the downwind distance X_i is:

$$X_i = (\cos \alpha) \sqrt{x_i^2 + y_i^2} \qquad \text{(B-5)}$$

The sampling time for high volume samplers was about 45 minutes and five different samplers were used to monitor at S_0, S_1, S_2, S_3, and S_4.

Prior to sampling the high volume samplers were calibrated by use of a calibrating orifice assembly and water manometer. (These calibration units were adjusted with a positive displacement meter.) A chart was then drawn of airflow versus static pressure. After the orifice was attached to the unit, the airflow was varied by the addition of perforated plates across the airflow stream. A calibration curve was then plotted relating airflow readings to actual flow in nonmetric units.

Prior to sampling, each filter was inspected for imperfections, desiccated in a balance room, and weighed to the nearest milligram in a weighing chamber. The tare weight was then recorded and the filter holder labeled.

Nuclepore® membrane filters were used for sample collection. Their relatively low tare weight (500 mg) and high flow capacity (0.036 m^3/min-cm^2, 93.3 kPa pressure drop) in comparison with similar filters enabled the particulate collected to comprise a higher percentage of tare weight and thus provide results within the measurable range. The high volume samplers collected particles less than 100 μm in size. Weights were determined to the nearest milligram, airflow rates to the nearest 0.005 m^3/s, and time to the nearest 5 minutes. After particulate matter on the filters was weighed (subtracting the tare weight), the mass concentration of suspended particulate was computed with the volume of air sampled.

Volume was determined from the initial and final airflow readings. These rotometer values were recorded on the form shown in Table B-3 along with the wind speed and direction. (These readings are converted to m^3/min through an appropriate calibration curve.) The volume of air sampled was then determined as follows:

$$V_a = \frac{(Q_i + Q_f)\ t_s}{2} \qquad \text{(B-6)}$$

where V_a = air volume sampled, m^3
Q_i = initial airflow rate, m^3/min
Q_f = final airflow rate, m^3/min
t_s = sampling time, min

Once the volume was determined and the final weight of the filters established, the mass concentration of particulates was determined by:

$$\chi = \frac{(W_f - W_i) \times 10^6}{V_a} \qquad \text{(B-7)}$$

where χ = mass concentration of particulate, μg/m^3
W_i = initial (tare) weight of filter, g
W_f = final weight of filter, g
V_a = volume of air sampled, m^3
10^6 = conversion of g to μg

The mass concentration of particulate collected at reference sampler S_0 was first subtracted from the mass concentration of the other samplers (S_1, S_2, S_3, and S_4) to yield the net particulate concentration due to the quarrying activities. Mass concentrations are reported to the nearest μg/m^3.

Table B-3. FUGITIVE DUST SAMPLER AND METEOROLOGICAL DATA LOG

Date Run Page

Time (24 hr clock)	Wind Speed mph avg.	Wind Speed mph range	Wind Direction Compass degrees avg.	Wind Direction Compass degrees range	S_1 Roto cfm	S_1 Act cfm	S_2 Roto cfm	S_2 Act cfm	S_3 Roto cfm	S_3 Act cfm	S_4 Roto cfm	S_4 Act cfm	Other comments
Totals													
Average													
Total elapsed time													Sampling crew

Mass emission rate was then calculated as an average of the calculations done for N sampler readings using Turner's equation for a ground level source with no effective plume rise (23) (Equation B-8):

$$Q = \frac{1}{N} \sum_{i=1}^{N} \frac{\chi_i \pi \sigma_y \sigma_z u}{\exp\left[-\frac{1}{2}\left(\frac{Y_i}{\sigma_y}\right)^2\right]} \qquad \text{(B-8)}$$

where Q = emission rate, g/s

χ_i = net ground level concentration at $(X_i, Y_i, 0)$, g/m^3

σ_y, σ_z = standard deviation of plume concentration distribution in the horizontal and vertical planes, respectively, m

u = arithmetic mean wind speed, m/s

π = 3.14

Y_i = lateral distance (Figure B-1)

X_i = downwind distance from source along dispersion centerline (Figure B-1)

The validity of applying this equation for determining emission rates is discussed in section 4 of Appendix C.

A meteorological station was employed to monitor the wind speed (u), direction, and temperature. Wind speeds were averaged every minute with a mean recorded for each 15-minute interval. The mean wind speed (u) was calculated from the average of the 15-minute recordings over the entire run. The wind direction variation was less than ±0.785 rad (±45°) from the centerline during the samplings. Continuous functions are used to calculate the atmospheric stability class. These functions are listed in Tables B-4 (24) and B-5 (25).

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(23) Turner, D. B. Workbook of Atmospheric Dispersion Estimates, 1970 Revision. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

(24) Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 6:859-863, March 1972.

(25) Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

TABLE B-4. CONTINUOUS FUNCTION FOR LATERAL ATMOSPHERIC DIFFUSION COEFFICIENT σ_y (24)

$$\sigma_y = AX^{0.9031}$$

Stability class	A
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

TABLE B-5. CONTINUOUS FUNCTION FOR VERTICAL ATMOSPHERIC DIFFUSION COEFFICIENT σ_z (25)

$$\sigma_z = AX^B + C$$

Usable range	Stability class	Coefficient		
		A_1	B_1	C_1
>1,000 m	A	0.00024	2.094	-9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		A_2	B_2	C_2
100 - 1,000 m	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		A_3	B_3	C_3
<100 m	A	0.192	0.936	0
	B	0.156	0.922	0
	C	0.116	0.905	0
	D	0.079	0.881	0
	E	0.063	0.871	0
	F	0.053	0.814	0

2. PORTABLE DUST MONITORING

A GCA Model RDM 101-4 respirable dust monitor[a] was used to sample the downwind concentration of particulates from the various unit operations of the processing activity. This is an advanced instrument for on-the-spot measurement of mass concentrations of respirable (<10 μm) particulates or total mass loading of particulates. It is a portable and fully automated unit with direct digital readout of the mass concentration of airborne particulates. Readings of 4 minutes to 30 minutes can be taken, and a traverse of points around a source of interest can be accomplished quickly. Results are obtained by electronic measurement of the beta absorption of the collected sample. A cyclone collection system is used as a first stage for removal of the >10-μm particulates.

During the GCA sampling, using the sampling apparatus shown in Figure B-4, all the data for each unit operation were recorded on the form shown in Table B-6. For each concentration reading the

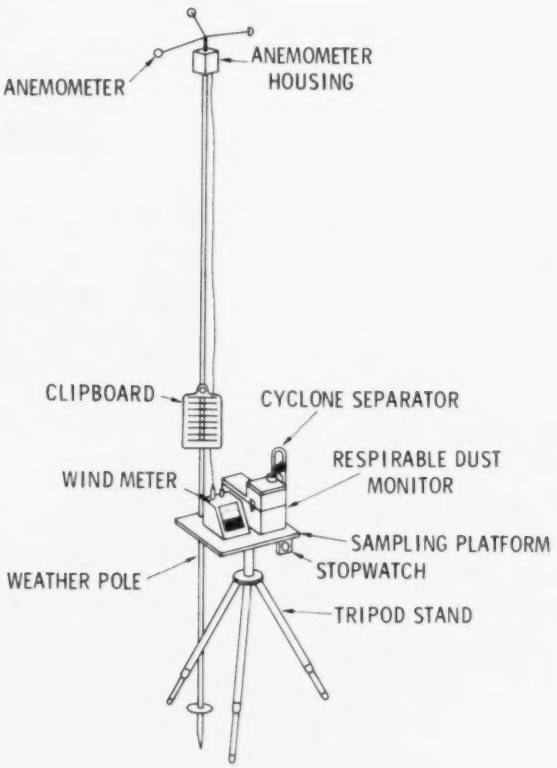

Figure B-4. Sampling apparatus.

[a]GCA Corporation, Bedford, Massachusetts.

TABLE B-6. FIELD DATA FORM

DATE _____

MODEL: POINT = 1
LINE = 2
DOSE = 3

SOURCE TYPE _____ BY _____

UNIT OPERATION	WIND SPEED, MPH	DISTANCE, FT. X	Y	Z	TIME, MIN.	READ., mg/m^3	CONC. $\mu g/m^3$	R/T	BGD, $\mu g/m^3$	Δ, $\mu g/m^3$	Q, g	S'	M	COMMENTS
TIME OF DAY														
ATM. STABILITY														

TOTAL SAMPLING TIME	MULTIPLY READING BY
4 MINUTES	1
8 MINUTES	0.46
16 MINUTES	0.23
20 MINUTES	0.184
30 MINUTES	0.122
37 MINUTES	0.1

mean wind speed was determined by averaging 15-second readings of the wind meter. This meter was connected to an anemometer set atop a 3.05-m (10-ft) pole. The downwind distance, X, was measured by physically pacing the shortest length to the source. Periodically the time and atmospheric stability class (using Figure B-2) were recorded on the bottom of the form. The terms listed on the form are explained in Table B-7. Any factors that may have affected concentration or emission rates were mentioned in the column labeled "Comments."

TABLE B-7. EXPLANATION OF FIELD DATA FORM TERMS

Term (units)	Meaning
Read (mg/m^3)	Digital readout of concentration
Conc. ($\mu g/m^3$)	Converted concentration for sampling times greater than 4 minutes (per list in lower right hand corner of form)
R/T	R = respirable reading T = total mass reading
BGD ($\mu g/m^3$)	Background concentration
Δ ($\mu g/m^3$)	The difference between the converted concentration and the background
Q (g or g/s)	Calculated emission rate
S'	Stability for the time and day the unit operation was sampled
M	The model used and referenced as 1, 2, or 3 (point, line, or dose, respectively)

When this form was completed it was programmed into an APL system computer and the emission rate, Q, was calculated in accordance with the model specified in column "M." The dose model refers to the concentration multiplied by the time of operation.

3. ANALYSIS

The emissions from sampling were analyzed for free silica, fibers, and trace elements. After the Nuclepore filter was weighed, one portion was selected for microscopy examination and another for composition analysis. X-ray fluorescence was chosen to give a semiquantitative determination of particulate composition.

a. Principle of X-Ray Fluorescence (XRF) Analysis

XRF analysis is based on measuring individual, characteristic x-rays for each element in a sample by energy dispersive techniques. These secondary fluorescent x-rays are generated by

irradiating the specimen with a primary source of x-rays using either a tungsten or rhodium target x-ray tube. All secondary x-rays are detected simultaneously with a silicon semiconductor detector. By using suitable amplifiers and an x-ray energy distribution analyzer, the characteristic x-rays for each element are electronically separated based on their energy and are displayed in either a spectral or alpha-numeric mode via video monitor. The data are also stored in a computer memory for additional data improvement or for on-line computerized data reduction and presentation in a teletype print-out.

An on-line computer is used for data reduction. Computer programs enable manipulation of spectral data to eliminate interfering lines, to integrate peaks, to subtract backgrounds, to correct for inter-element and matrix effects, and to provide a variety of quantitative conversion equations to reduce raw counts to elemental concentration.

b. Applicability of XRF

The XRF technique is applicable to qualitative and quantitative elemental analyses (sodium to uranium) for solids (whole sections or powdered) and liquids (including solids in solution). In the specific case of particulate collected on filters, the direct measurement of these specimens can provide a detection limit of $<0.2\ \mu g/cm^2$ with sample loadings of $1.2\ \mu g/cm^2$. The detection limit is influenced by many factors including energy of the x-rays being emitted by the elements, matrix, counting times, excitation source, and sample chamber atmosphere. For particulate on filter paper with a loading of $1.2\ \mu g/cm^2$ and with a rhodium excitation source, the following detection levels can be attained:

Element	Detection level, $\mu g/cm^2$
P	0.20
S	0.11
K	0.15
Ca	0.06
Cr	0.06
Fe	0.05
Ni	0.05
Cu	0.05
Zn	0.04
As	0.04
Br	0.07
Cd	0.13
Ba	0.13
Hg	0.08
Pb	0.07

c. XRF Apparatus

The analytical system used in these measurements is composed of an EDAX International, Inc. Mark II Basic EDAM System, an EDAX Model 707A Super Analyzing Unit, a Data General Corp. 12 K Computer (Nova 1220), and a Teletype 33TC. Either a rhodium or tungsten target x-ray tube is available. The system can be operated with the sample maintained in vacuum or in a helium purged atmosphere. Samples up to 76 mm (3 in.) in diameter can be analyzed.

d. Calibration of XRF Equipment

Quantitative analysis with the x-ray technique is based on using reference standards of known concentrations of the desired elements in a matrix similar to that of the unknown specimens, or using mathematical corrections through computer programs to correct for inter-element and matrix effects.

If a range of standards is available, it is possible to establish a working curve for each element which is a plot of concentrations in micrograms (or $\mu g/cm^2$) vs. the intensity of the x-rays characteristic of each element. If the range of standards is not available, the ratio of the intensity of the peak of unknown concentration of an element to the intensity of the peak of a known concentration of that same element will provide a reliable semiquantitative analysis (± 50% or less of the amount present).

Standards are prepared by precipitation or deposition of NBS Standard Research Materials, metal oxides or salts, or portions of "loose" particulate collected during long-term sampling. In the latter case, emission spectrographic analysis of this material serves to provide the needed compositional information for preparing standards. Several deposition procedures are used for preparing semiquantitative standards including the filtration of particulate suspended in carbon tetrachloride and the filtration of particulate suspended in gas matrix or deposited from solution.

Other semiquantitative measurements of particulate collected on filters are made by correlatng the x-ray fluorescence responses of test samples with emission spectrographic analyses of ash for one or more of the test specimens in a set. This correlation serves to provide a semiquantitative means of rapidly analyzing large numbers of filters by XRF without going through an ashing step, which is required for emission spectrographic analyses of filters with low loadings.

e. Procedure for XRF Analysis

Based on the type of sample matrix and the elements being measured, the excitation source and the x-ray excitation voltage are selected. Either a helium flush or vacuum is applied to the

sample chamber, and proper selection of the energy range is made to optimize response. The filter specimen is analyzed by counting the secondary x-rays for 100 seconds to 2,000 seconds, depending on quantity of material on the filter.

The spectral data are manipulated by computer software to smooth the statistical channel-to-channel fluctuations in the spectrum, subtract background or spectra characteristic of residual trace elements in the filter, strip a series of peaks characteristic of specific elements, and obtain quantitative or semiquantitative data by comparing the spectral intensity of the test specimen with the known values of the standard samples.

The computer provides the resulting values (quantitative or semi-quantitative) in $\mu g/cm^2$ or comparable notation as programmed.

f. Quantitative Determination of Free Silica as Quartz

The permissible concentration for respirable silica-containing dusts is computed based on measuring the quartz content and using the formula (26).

$$\text{permissible dust } (mg/m^3) = \frac{10}{\% \text{ quartz} + 2} \qquad \text{(B-9)}$$

The percent crystalline quartz is determined on a respirable-size fraction of the dust. At present, there is no one acceptable method for the quantitative determination of quartz in air samples, but there are five general methods which can be applied to the quantitative analysis of filter samples for quartz: x-ray diffraction; differential thermal analysis; colorimetry; optical microscopy and petrography; and infrared spectrophotometry. In addition, there are several variations for each method. The techniques and potential limitations are reviewed in a number of articles, including those by Larsen et al. (27) and Freedman et al. (28).

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(26) Aerosol Technology Committee. Guide for Respirable Mass Sampling. American Industrial Hygiene Association Journal, 31:133, January-February 1970.

(27) Larsen, D. M., L. J. Von Doenhoff, and J. V. Crable. The Quantitative Determination of Quartz in Coal Dust by Infrared Spectroscopy. American Industrial Hygiene Association Journal, 33:367-372, June 1972.

(28) Freedman, R. W., S. Z. Toma, and H. W. Lang. On-Filter Analysis of Quartz in Respirable Coal Dust by Infrared Absorption and X-Ray Diffraction. American Industrial Hygiene Association Journal, 35:411-418, July 1974.

Wet chemical procedures such as the Talvitie Method employing phosphoric acid, differential thermal analysis, optical microscopy, and petrographic analysis are inaccurate, insensitive, and time consuming (29, 30).

Infrared spectrophotometry and x-ray diffraction appear to be the best techniques available (23, 31). The x-ray diffraction technique for determining quartz is adversely affected by interfering crystalline material (e.g., muscovite, potash feldspar (microcline), plagioclase, mica (biotite), sillimanite, graphite, and aragonite) and by x-ray background scatter from filters.

Little interference is encountered when using infrared spectrophotometric techniques. (In these techniques, the only spectral interference in the analytical region, 850 cm^{-7} to 750 cm^{-7}, occurs if sample ashing of kaolin-containing specimens is performed at temperatures in excess of 600°C.)

The infrared spectrophotometric approach was chosen for this study. Although several procedures can be adapted to these types of specimens, the method developed by Cares et al. (32) was used for determining quartz in airborne respirable granite dust. The method involves ashing of the filter and sample at 550°C and mixing and pressing the sample ash with KBr to form a solid pellet which is placed in an infrared spectrophotometer for spectral analysis. The detailed analytical procedure is as follows:

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(29) Durken, T. M. Determination of Free Silica in Industrial Dust. Journal of Industrial Hygiene and Toxicology, 28: 217, February 1946.

(30) Edwards, G. H. Comparison of X-Ray Diffraction, Chemical (Phosphoric Acid), and Dispersion Staining Methods for the Determination of Quartz. American Industrial Hygiene Association Journal, 26:532, September-October 1965.

(31) Freedman, R. W. Recent Advances in the Analysis of Respirable Coal Dust for Free Silica, Trace Elements, and Organic Constituents. Annals of the New York Academy of Sciences, 200:7-16, December 1972.

(32) Cares, J. W., A. S. Goldin, J. J. Lynch, and W. A. Burgess. The Determination of Quartz in Airborne Respirable Granite Dust by Infrared Spectrophotometry. American Industrial Hygiene Association Journal, 34:298-305, July 1973.

1. Collect the sample in the field with a size selective sampler equipped with a low ash polyvinyl chloride membrane filter which has excellent moisture stability (Mine Safety Appliances Co. Membrane Filter, Part No. 62513 or equivalent.) (The infrared spectrum of the ash from the MSA filter does not interfere with the quartz determination.)

2. Place the filters in porcelain evaporating dishes (Coors 4/0) and transfer them to a muffle furnace.

3. Heat to 550°C and maintain until the carbon is destroyed (about 1-1/2 to 2 hours).

4. Remove the dishes carefully, cover, and cool.

5. Add 40 ± 5 mg of infrared-quality KBr (Harshaw Chemical Co., Cleveland, Ohio) previously ground to minus 200 mesh and kept in an oven at 110°C. (If sample weight is excessive, a larger amount of accurately weighed KBr should be added, and aliquots taken for final sample.)

6. Mull the sample ash and KBr with a small Alundum pestle until they are thoroughly mixed. Take care not to apply pressure or grind, which may alter the spectrum.

7. With a spatula, transfer the mixture as completely as possible to a pellet press equipped with a 6.4-cm (1/4-in.) diameter punch and die.

8. Tap lightly to distribute the powder evenly, center the punch carefully, and press. Release the pressure, turn the die about 3.14 rad (180°), and repeat the pressing. With good technique a clear pellet without cracks or opaque spots will be obtained.

9. Transfer the pellet to a pellet holder and place the mounted pellet in the sample beam of an infrared spectrophotometer (Perkin-Elmer Model 421 Grating Spectrophotometer or equivalent).

10. At a wavelength of about 11.8 μm and wide slit, adjust the base line to a maximum transmission (or minimum absorbance) and scan to 13 μm. For identification purposes it may be necessary to observe the 14-μm quartz band. Reverse the sample for a repeat scan.

11. To obtain the weight of quartz in the sample, subtract the absorbance of the base line at 12 μm from that at 12.5 μm and compare the net absorbance with a calibration curve obtained from a series of quartz-KBr standards. Absorbances should be below 0.5 for satisfactory linearity. Samples of greater absorbance are brought into this range

by breaking up the pellet, diluting it with KBr, and aliquoting if necessary. Assuming 100% sample recovery with a minimum possible measurement of absorbance of 0.02, the detection limit is approximately 5 µg of quartz in a sample.

Preparation of calibration standards is done as follows:

1. Prepare quartz standards from 5-µm grade Minusil R, a high-purity crystalline silica obtainable in several size ranges from the Pennsylvania Glass Sand Corp., Pittsburgh. Ninety-eight percent of the particles of this grade are less than 5 µm in diameter.

2. Place the standards in a muffle furnace, and heat them to the same temperature as the samples before use.

3. Prepare stock standards by blending carefully weighed amounts of Minusil and R-grade KBr either by mulling with an Alundum mortar and pestle or by use of a commercial type of mixer such as the "Wig-L-Bug."

4. Dilute the stock mixture in the same manner to obtain concentrations which will yield 40 mg of pellets containing from 5 µg to 150 µg of quartz.

5. Press pellets and record spectra in the same manner as with the samples.

6. Plot calibration curve of net absorbance versus weight of quartz.

g. Quantitative Determination of Fiber

A fiber count was done for the samples collected on the high-volume filters. The sample preparation and counting procedures are given below:

(1) Sample Preparation--
The counting medium consists of 50 mg of membrane filter dissolved per 50 ml of a solution of one to one (vol.) dimethyl phthalate and diethyl oxylate. Fibers are counted on wedge shaped sections cut from the filter and mounted on a clean 25 mm x 75 mm glass microscope slide. A drop of counting medium is placed on the slide, dust side up. The wedge is then covered by a No. 1 1/2 cover slip. Care is taken to avoid trapping air. Counting of fibers is started after 30 minutes and completed within 2 days to avoid fiber migration and crystal growth. A microscope equipped with phase-contrast capabilities, a 4-mm "high dry" phase-contrast objective (40X to 45X), and a 10X eyepiece are used to count the sample.

(2) Counting--
A fiber is defined as a particle 5 μm long with length three times the diameter. One side of the wedge is arbitrarily chosen as the 'counting' side. Fibers entering the area from either of the other two sides are not counted. Touching fibers (fibers with one end touching another fiber regardless of the resulting angle) are considered as one. Fibers crossing each other are counted individually. A minimum of 20 fields are counted. Counting is terminated after 100 fields have been searched.

(3) Calculations--
The concentration of fibers is calculated as:

$$\chi_{fibers} = \frac{fibers \cdot R'}{fields \cdot V} \qquad \text{(B-10)}$$

where χ_{fibers} = concentration of fibers per ml of air

fibers = total number of fibers counted

fields = total number of fields counted

R' = filtration area divided by area of a counting field

V = sample volume of air, ml

APPENDIX C

SAMPLING RESULTS AND ERROR ANALYSIS

The purpose of sampling is to obtain an estimate of the overall plant emissions and also the relative contributions of the various unit operations. This appendix describes the sites that were selected for sampling, the results of the sampling effort, the emission factors determined, and an estimate of the error associated with the emission rate data.

Two crushed traprock facilities were chosen whose operations are representative of the crushed stone industry. Traprock accounts for 68% of total crushed stone production. Further, these plants were located in areas with meteorological conditions favorable for sampling.

1. SITE DESCRIPTION

a. Plant A

(1) Blasting and Drilling--
At the blasting site, holes are drilled in the rock in a square pattern, with water applied at the drill face. These holes are then charged with ANFO (ammonium nitrate and fuel oil) and dynamite, and the rock is blasted away.

(2) Quarrying--
A shovel and front-end loader dump blasted material onto haul trucks. The front-end loader is also used to reposition material that facilitated use of the shovel. Three trucks are used to haul the rock on an unpaved road to a hopper.

(3) Primary Crushing and Unloading--
Material is fed by gravity from the hopper into the primary crusher. This unit fragments the rock down to a top size of 150 mm to 180 mm (6 in. to 7 in.) in diameter. Crushed material is transferred via belt conveyor to a storage pile.

(4) Processing Activities--
The process begins with material conveyed from the stockpile generated by the primary crusher. This aggregate has a top size of 0.25 m (10 in.) and is transferred by tunnel belt conveyor to the first screen tower. Undersize material at the tower is gravity loaded into a bin that is periodically gravity unloaded

onto trucks. Oversize stone is either chute fed into a 2.1-m (7-ft) cone crusher which breaks the aggregate down to a top size of 0.1 m (3 to 4 in.), or belt conveyed by a stacker to a surge pile. Material from this pile is belt conveyed to the next screen tower where undersize material falls into the bin for unloading, and oversize material is crushed by a 1.7-m (5 1/2-ft) crusher to a top size of 44 mm (1 3/4 in.) and belt conveyed to a third screen tower. At this tower, undersize material is also bin fed to trucks. Oversize stone is crushed to a top size of 16 mm (5/8 in.) and belt conveyed to the conveyor feeding the screen for resizing.

Trucks loading at the screen stations are positioned under the bins and the bottom gates are opened, letting stone fall by gravity into the trucks. The stone is then transported on unpaved roads to the appropriate stockpile. Front-end loaders work in the area, smoothing the tops of the stockpiles and filling customer trucks that enter. These vehicles all travel on unpaved roads. A tank truck also circulates throughout this facility, spraying water on the roads for dust suppression.

The plant operates for about 4.5 hr/day, 2 days/wk. The processing rate through the primary crusher is about 545 metric tons/hour.

The sampling data and results are given in Table C-1.

b. Plant B

The blasting, quarrying, and primary crushing activities are similar to those at Plant A; hence, only the processing activities are described.

At the processing plant, material from the stockpile generated by the primary crusher is fed by belt conveyor to a scalper screen. This unit feeds the oversize material to a 1.67-m (5 1/2-ft) secondary crusher. The crushed material and the undersize have a top size of 82 mm (3 to 3 1/2 in.). This aggregate is then fed by belt conveyor to another screen. Undersize passing through the screen falls into a hopper that is unloaded whenever trucks are positioned underneath, or it is belt conveyed to a surge pile. Oversize material is gravity chute fed into two crushers, 0.91-m (3-ft) and 1.22-m (4-ft) shortheads, connected in series. The use of both units is dependent on the size of aggregate being run.

Crushed material, 38 mm to 44 mm (1 1/2 in. to 1 3/4 in.), is transferred from here by belt conveyor to two screens. Undersize stone falls by gravity into two hoppers and is loaded onto trucks periodically. Oversize material is loaded by gravity chute into a crusher, a 1.22-m (4-ft) shorthead, from which the crushed material is conveyor fed back to the conveyor originally

TABLE C-1. PRODUCTION OF CRUSHED STONE - PLANT A

UNIT OPERATION	U	X	Y	Z	TIME - CHI		Q	UNITS	S
QUARRYING	17.0	615.0	0.0	30.0	45.0	169.0	1.602E0	(G/SEC)	C
QUARRYING	17.0	791.0	0.0	0.0	45.0	135.0	1.595E0	(G/SEC)	C
PRMRY CRUSHER + UNLO	17.0	100.0	0.0	0.0	12.0	648.0	1.808E-1	(G/SEC)	C
SCNDRY CRUSHER + SCR	8.0	123.0	0.0	0.0	4.0	554.0	1.057E-1	(G/SEC)	C
SCNDRY CRUSHER + SCR	8.0	123.0	0.0	0.0	8.0	221.0	4.218E-2	(G/SEC)	C
SCNDRY CRUSHER + SCR	8.0	123.0	0.0	0.0	4.0	280.0	5.344E-2	(G/SEC)	C
FINES CRUSHER + SCRF	8.0	123.0	0.0	0.0	4.0	114.0	2.176E-2	(G/SEC)	C
CONVEYING	2.0	110.0	0.0	20.0	4.0	40.0	1.709E-2	(G/SEC)	C
CONVEYING	2.0	110.0	0.0	20.0	4.0	614.0	2.624E-1	(G/SEC)	C
UNLOADING TRUCK	8.0	210.0	0.0	0.0	4.0	10.0	5.021E-3	(G/SEC)	C
UNLOADING TRUCK	8.0	70.0	0.0	0.0	4.0	80.0	5.511E-3	(G/SEC)	C
UNLOADING TRUCK	8.0	70.0	0.0	0.0	4.0	204.0	1.405E-2	(G/SEC)	C
UNLOADING TRUCK	8 0	210.0	0.0	0.0	4.0	4.0	2.008E-3	(G/SEC)	C
LOADING TRUCK	8.0	123.0	0.0	0.0	4.0	74.0	3.390E0	(G)	C
LOADING TRUCK	17.0	40.0	0.0	0.0	8.0	28.0	1.490E-3	(G/SEC)	C

U = mean wind speed, mph

X, Y, Z = dispersion coordinates (Figure B-1)

Q = emission rate in units shown

S' = stability class

chi = χ = concentration at X, Y, Z

Time = sampling time, min

feeding the screens. All undersize material not guided into the hopper is transferred by belt conveyor to a surge pile. The aggregate top size at this point is 32 mm (1 1/4 in.). Material from the surge pile is conveyed by belt conveyor in a tunnel to a screen, then separated into four sizes: 32 mm, 19 mm, 13 mm or 5 mm (1 1/4 in., 3/4 in., 1/2 in., or 3/16 in.). Any oversize stone is fed by gravity to a gyradisc. This crushed material is then belt conveyed onto the belt originally feeding the screens for sizing. Undersize material is gravity loaded into a hopper.

Trucks then pull under the hopper for loading, then transfer the material on unpaved roads to the appropriate stockpiles. All trucks traveling from the load-out stations, and customer trucks that have been weighed, travel on unpaved roads to the stockpile areas. Empty trucks drive onto the stockpile and are filled by a front-end loader. The front-end loader travels on unpaved roads throughout the storage area either loading trucks or smoothing out the tops of stockpiles. Loaded customer trucks and trucks to be loaded leave the stockpile area and travel to their respective destinations on unpaved roads. Tank trucks spray water on the ground continuously to suppress dust formation.

The plant operates for about 6 hr/day, 5 days/wk. The processing rate through the primary crusher is about 645 metric tons/hr. The remaining crushers operate for about 9.5-hr/day at 2 days/wk.

The sampling data and results from the computer (in accordance with input of Figure B-4) are given in Table C-2.

2. EMISSION FACTORS

The emission factors for respirable and total particulate emissions were summarized earlier in Table 3 (Section IV). The emission factors were derived using the results of sampling, as:

Emission factor = (Emission rate)÷(Production rate)

a. Blasting

The amount of rock blasted was 19,970 metric tons (21,963 tons). At average emission doses of 180 g of respirable particulates and 1,070 g of total particulates, the emission factors for respirable and total particulates are 0.0088 and 0.0522 g/metric ton, respectively.

b. Drilling

The emission factor for drilling was determined by using the sampling data from crushed granite operations, a separate study under contract 68-02-1874. Four readings of ground level concentration were obtained at a wind speed of 0.9 meter/second under D atmospheric stability conditions, 27 meters from the

TABLE C-2. PRODUCTION OF CRUSHED STONE - PLANT B

UNIT OPERATION	U	X	Y	Z	TIME	CHI	Q	UNITS	S'
BLASTING	8.0	204.0	0.0	0.0	16.0	393.0	1.798E2	(G)	C
BLASTING	8.0	204.0	0.0	0.0	55.0	678.0	1.066E3	(G)	C
SCNDRY CRUSHER + SCR	5.3	70.0	0.0	10.0	4.0	742.0	1.242E-1	(G/SEC)	B
SCNDRY CRUSHER + SCR	5.3	70.0	0.0	10.0	12.0	418.0	6.995E-2	(G/SEC)	B
SCNDRY CRUSHER + SCR	5.3	70.0	0.0	10.0	4.0	590.0	9.874E-2	(G/SEC)	B
SCNDRY CRUSHER + SCR	5.3	70.0	0.0	10.0	12.0	198.0	3.314E-2	(G/SEC)	B
TERTIARY CRUSHER + S	5.3	123.0	0.0	0.0	4.0	50.0	1.191E-2	(G/SEC)	B
TERTIARY CRUSHER + S	5.3	123.0	0.0	0.0	4.0	272.0	6.479E-2	(G/SEC)	B
FINES CRUSHER + SCRE	5.3	130.0	0.0	0.0	4.0	27.0	7.115E-3	(G/SEC)	B
FINES CRUSHER + SCRE	5.3	130.0	0.0	0.0	4.0	10.0	2.635E-3	(G/SEC)	B
UNLOADING TRUCK	5.3	123.0	0.0	0.0	4.0	140.0	8.003E0	(G)	B
UNLOADING TRUCK	5.3	70.0	0.0	0.0	4.0	10.0	2.043E-1	(G)	B
UNLOADING TRUCK	5.3	90.0	0.0	0.0	4.0	25.0	8.081E-1	(G)	B
UNLOADING TRUCK	5.3	100.0	0.0	0.0	8.0	28.0	2.194E0	(G)	B
UNLOADING TRUCK	5.3	90.0	0.0	0.0	4.0	20.0	6.465E-1	(G)	B
UNLOADING TRUCK	5.3	70.0	0.0	0.0	4.0	22.0	4.495E-1	(G)	B
UNLOADING TRUCK	5.3	90.0	0.0	0.0	4.0	672.0	2.172E1	(G)	B
UNLOADING TRUCK	5.3	100.0	0.0	0.0	8.0	27.0	2.116E0	(G)	B
UNLOADING TRUCK	5.3	90.0	0.0	0.0	4.0	72.0	2.327E0	(G)	B
LOADING TRUCK	5.3	90.0	0.0	0.0	4.0	222.0	7.176E0	(G)	B
LOADING TRUCK	5.3	90.0	0.0	0.0	4.0	80.0	2.586E0	(G)	B

U = mean wind speed, mph

X, Y, Z = dispersion coordinates (Figure B-1)

Q = emission rate in units shown

S' = stability class

chi = χ = concnetration at X, Y, Z

Time = sampling time, min

source. The concentration, 6.7 meters from the centerline was 70, 130, and 130 micrograms per cubic meter and 560 micrograms per cubic meter on the plume centerline. The calculated emission rates were 11.59, 21.52, 21.52 and 67.28 milligrams per second, respectively. The average emission rate from wet drilling in such operations is 0.015 g/s. At an average rate of 2 hr/hole, 30 holes/blast, and 19,970 metric tons/blast, the emission factor for total particulates is 0.158 g/metric ton. It is assumed (based on sampling at granite operations) that 10% of the particulate is respirable, yielding an emission factor of 0.0158 g/metric ton.

c. Quarrying

The average emission rate for total particulates is 1.60 g/s. At a production rate of 533 metric tons/hr (586 tons/hr), the emission factor is 10.5 g/metric ton. It is assumed (based on sampling at crushed granite operations) that 10% of the particulate is respirable, resulting in an emission factor of 1.05 g/metric ton.

d. Primary Crushing and Unloading

The emission rate for respirable particulates is 0.178 g/s. The crushing and unloading operations occurred for 12 minutes, thus yielding a dose of 128 g of respirable particulates. Three 32-metric ton (35-ton) trucks were unloaded into the crusher during this 12-minute interval. The emission factor is thus 1.34 g/metric ton.

e. Secondary Crushing and Screening

At Plants A and B two average respirable emission rates of 0.048 g/s and 0.066 g/s at production rates of 533 metric tons/hr and 631 metric tons/hr (694 tons/hr), respectively, resulted in a mean emission factor of 0.342 g/metric ton. The 95% confidence limits are ±0.324 g/metric ton. Two total emission rates for Plants A and B, of 0.1057 g/s and 0.097 g/s, respectively, produced a mean emission factor of 0.62 g/metric ton ± 0.997 g/metric ton at the 95% confidence level.

f. Tertiary Crushing and Screening

At Plant B's production rate of 631 metric tons/hr, the respirable particulate emission rate is 0.0119 g/s. The emission factor is thus 0.0665 g/metric ton. The total particulate emission rate is 0.0648 g/s (at Plant B) with an emission factor of 0.362 g/metric ton.

g. Fines Crushing and Screening

Two total emission rates, 0.0218 g/s and 0.00712 g/s, were calculated at Plants A and B, respectively. At the production rates of 533 metric tons/hr and 631 metric tons/hr, the mean emission factor for these two plants is 0.0918 g/metric ton ± 0.662 g/metric ton at the 95% confidence level. The respirable emission rate from Plant B is 0.00263 g/s, resulting in a factor of 0.0147 g/metric ton.

h. Conveying

At Plant A emission rates of 0.0171 g/s and 0.262 g/s for respirable and total particulates, respectively, yield emission factor of 0.113 g/metric ton and 1.73 g/metric ton.

i. Unloading of Trucks

At Plant B the 2.37-g respirable emission dose, based on the unloading of a 32 metric ton truck, gives a factor of 0.0746 g/metric ton. At Plant A the respirable emission rate of 0.005 g/s at the production rate of 533 metric tons/hr produces a factor of 0.033 g/metric ton. The mean emission factor is 0.0538 ± 0.264 g/metric ton at the 95% confidence level. For total particulates, at Plant B the dosage of 6.65 g for a 32 metric ton truck yields a factor of 0.209 g/metric ton. At Plant A the mean emission rate of 0.00669 g/s at 533 metric tons/hr results in a factor of 0.0442 g/metric ton. The mean factor is 0.127 ± 1.05 g/metric ton (at the 95% confidence level).

j. Loading of Trucks

The mean dose rate for total particulates from both plants is 5.28 g. Loading a 32 metric ton truck gives a factor of 0.166 g/metric ton. The respirable particulate rates of 0.022 g/s and 0.00149 g/s yield a factor of 0.0453 g/metric ton.

k. Wet Unpaved Road Traffic

The diffusion equation used for unpaved road emissions is (33):

$$Q_L = D_t \sqrt{\frac{\pi}{2}}\, \sigma_z u. \qquad \text{(C-1)}$$
(C-1)

where D_t = dosage, $g \cdot s/m^3$

π = 3.14

u = wind speed, m/s

σ_z = vertical dispersion, m

Q_L = line dose rate, g/m

At a respirable particulate concentration of 20 $\mu g/m^3$, once a 240-second period, at a distance of 36.6 m and a wind speed of 1.25 m/s, two vehicles emit particulates at the rate of 0.00864 g/vehicle-meter. At a total particulate concentration of 114 $\mu g/m^3$, the emission rate is 0.0492 g/vehicle-meter. The respirable emission factor (E_R) is calculated for the average unpaved road distance of 750 meters traveled by the average of 17 vehicles per hour as follows:

$$E_R = \frac{\left(\frac{8.64 \times 10^{-3}\ g}{veh.\text{-}m}\right)\left(\frac{17\ veh.}{hr}\right) 750\ m}{533\ metric\ tons/hr} \qquad \text{(C-2)}$$

converted to:

$$E_R = 0.202\ g/metric\ ton$$

The total emission factor is calculated in the same manner to be 1.15 g/metric ton.

Using the data given in Appendix A.1, the emission factors for NO_x and CO were determined. At Plant A there were 20,426 metric tons of rock blasted using 6.08 metric tons of ANFO. Every kilogram of ANFO used creates 0.00625 cubic meters of NO_x. The emission factor was thus calculated and converted to 2.85 g/metric ton. For carbon monoxide, there was 0.00873 m^3 of CO

(33) Gifford, F. A., Jr. Chapter 3 - An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Alade, D. A. (ed.). Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. p. 445.

produced per kilogram of ANFO used, and the emission factor was 1.68 g/metric ton.

3. ANALYTICAL RESULTS

Results of the elemental, free silica, and fiber analyses are presented in Tables C-3, C-4, and C-5, respectively. The only hazardous constituent of the dust is the free silica (Table C-3). The mean free silica content is 1.57% (Table C-4). The emission factor for respirable and total particulates containing free silica is then computed from these data. However, if greater than 1% free silica is detected, the entire emissions are considered free silica - thus the emission factors are equivalent to the particulate emissions factors.

The fiber analysis of Table C-5 measured all fibers for preliminary analysis purposes. No attempt was made to determine which fibers were asbestos. At 62 meters downwind from the blasting operation, the fiber concentration was 5.4 fibers/ml (or 5.4×10^6 fibers/m^3).

4. COMPUTATION OF ERROR IN EMISSION RATE

The value of emission rate, Q, is determined in the field by application of Gaussian dispersion equations to the concentrations obtained with the high-volume and GCA samplers. These emission values have a standard deviation which is a function of the standard deviation of the variables. The emission rate is calculated using Turner's (23) estimates of atmospheric dispersion from ambient measurement of χ. In high-volume samplers, there is an error due to inconsistent airflow rates and there are errors in time measurements and weighing which are part of the emission error.

The values of atmospheric stability as reflected by the standard deviations (σ) in the horizontal and vertical planes are valid for a sampling time of 10 minutes. The vertical deviation is expected (23) to be correct within a factor of two for all stabilities out to a few hundred meters, and neutral to moderately unstable conditions in the lower 1,000 meters of the atmosphere with a marked inversion above for distances out to 10 kilometers or more. Since all GCA sampling was performed within a few hundred meters of the unit operations, these conditions were met. For the quarrying activity (high-volume samplers) the distance was greater; however, the emission rates calculated were within 0.6% of their mean calculated value.

The estimate of horizontal dispersion, σ_y, will be less uncertain than that of σ_z. The emission determined (for the three cases cited) will therefore be within a factor of three for variations of σ_y, σ_z and u (23). Hence, the overall standard deviation (σ) in determining emission rate can be estimated as follows:

TABLE C-3. ELEMENTAL ANALYSIS OF EMISSIONS FROM CRUSHED STONE QUARRIES[a]

(percent)

Element	Plant A, Quarry	Plant B		
		Blasting	Primary crusher	Plant activity
Silicon	4.8 to 14.3	3.0 to 9.1	11.8 to 35.3	6.3 to 18.9
Calcium	2.4 to 4.7	3.0 to 9.1	5.9 to 11.8	3.2 to 6.3
Sodium	4.8 to 14.3	3.0 to 9.1	5.9 to 11.8	6.3 to 18.9
Iron	2.4 to 4.8	1.5 to 3.0	5.9 to 11.8	3.2 to 16.3
Aluminum	2.4 to 4.8	1.5 to 3.0	5.9 to 11.8	3.2 to 16.3
Magnesium	0.33	0.9	2.4	1.9
Titanium	0.24	0.21	0.7	0.5
Tin	0.19	0.012	0.024	0.12
Chromium	0.14	0.012	0.47	0.01
Lead	0.1	0.012	0.51	0.19
Vanadium	0.1	0.06	0.035	0.025
Manganese	0.04	0.024	0.094	0.06
Copper	0.04	0.03	0.12	0.13
Nickel	<0.005	<0.006	0.005	0.006
Zirconium		<0.006	0.005	0.025
Silver		<0.003	0.007	0.025
Zinc			0.47	0.252
Molybdenum			0.24	0.044
Boron			0.12	

[a]Cation elemental analysis is shown as percent by weight of total material; oxides and carbonates predominate the anion form.

Note: Blanks indicate that element concentration is below the detection limit of the instrument.

TABLE C-4. FREE SILICA ANALYSIS FROM CRUSHED STONE QUARRIES

Sample	Free silica, %
Plant A	
Background	1.44
Quarrying	2.31
Blasting	2.43
Primary crusher	0.78
Mean	1.74
Plant B	
Plant activity	1.4
Mean of Plants A and B	1.57
Standard deviation	0.24
±95% Confidence interval	2.16

TABLE C-5. FIBER ANALYSIS FROM CRUSHED STONE QUARRIES

A fiber is a particle greater than 5 μm in length with an L/D_f of 3 or greater.

- Sampling results:

  Field area = 0.005 mm^2
  Count = 100 fields
  Average count per field (sample of blasting emission from Plant B) = 0.16

- Fiber concentration at 62 meters (204 ft) from the source = 5.4 fibers/ml

- Emission factor for fibers = $128 \times 10^6 \frac{\text{fibers}}{\text{metric ton}}$

- Maximum source severity (at 410 m) = 0.018

- Affected population due to emissions from a representative crushed stone plant = zero

$$\sigma \quad \sqrt{(\sigma_1)^2 + (\sigma_2)^2} \qquad \text{(C-3)}$$

where σ_1 = estimated population standard deviation from sampling for χ

σ_2 = additional standard deviation in calculation of Q from χ

A factor of three is defined as follows:

$$\frac{X' + \sigma_2}{X' - \sigma_2} = 3 \qquad \text{(C-4)}$$

where X' = any average value calculated or measured.

From Equation C-4, a factor of three in the calculation of Q implies:

$$\sigma_2 = 0.5\ X' \qquad \text{(C-5)}$$

Therefore, all values of emission rate computed in this document are correct within the "factor" as defined in the above discussion.

APPENDIX D

COMPARISON OF EMISSION RESULTS WITH PREVIOUS STUDIES

This appendix provides a comparison of the emission data obtained during this study to that reported earlier. The approaches that were used to determine the emission factors in each study are also briefly discussed.

Table D-1 gives the emission factors as determined by MRC sampling and also as estimated in the Compilation of Air Pollutant Emission Factors (34). As noted in the table, the MCR emission factors are two orders of magnitude less than those estimated in Reference (34). Possible explanations for these differences are given below.

MCR emission factors were determined by measuring ambient air concentrations around a source and calculating the emission rate using a dispersion equation. The samplers were placed about 30 m to 40 m away from the source and thus did not measure particles that settled between the source and the samplers. For a 4.47 m/s (10 mph) wind speed and an emission height of 3 m, particles greater than 74 μm settle within 35 m of the source.

The emission factors estimated in Reference (34) were based on the results of sampling the dust loading at the inlet of a baghouse (used to control dust emissions from various crushing and screening operations) and on the assumption that about 41% of the emitted particulates settle within the plant. This method has two shortcomings: first, the total particulate emission factor as determined by the dust loading at a baghouse inlet is itself an inflated value; second, the estimated fraction of settleable particulates is lower than the actual value.

A baghouse system, by virtue of its relatively high airflow velocity, pulls in particles which otherwise would not be airborne at all. Further, the higher airflow velocity coupled with the slight negative pressure in the ducting leading to the baghouse causes the evaporation of moisture that normally would

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(34) Compilation of Air Pollutant Emission Factors. Office of Air Programs Publication No. AP-42, U.S. Environmental Protection Agency. Research Triangle Park, North Carolina, February 1972.

TABLE D-1. EMISSION FACTORS OBTAINED FROM TWO STUDIES

Operation	Reference 34			MRC		
	Uncontrolled total emissions, g/metric ton	% Settling in plant	Suspended emissions, g/metric ton	Total particulate emissions, g/metric ton	% Respirable emissions	Respirable emissions, g/metric ton
Primary crushing	250	80	50	13	10	1.3
Secondary crushing and screening	750	60	300	1	55	0.6
Tertiary crushing and screening	3,000	40	1,800	0.4	18	0.1
Fines milling	3,000	25	2,250	0.1	16	0.2
Recrushing and screening	2,500	50	1,250			
TOTAL	9,500	41	5,605	14.5	15	2.2

Note: Blanks indicate no data reported.

bind the smaller particles together. This enables the fine and smaller particles to break away and escape into the atmosphere. Finally, the heavier particles collide with each other, breaking up into smaller and finer particles. Obviously, an emission factor for total particulates that is based on the dust loading at the inlet to a baghouse is thus an inflated value that does not represent the uncontrolled emissions.

Since details on particle-size distribution are not available, it is difficult to estimate the fraction of settleable particulates. However, by comparing the uncontrolled total particulate emissions with the MRC value for total particulate emissions it can be seen that the fraction used should have been 99% plus and not 41% as assumed in estimating the emission factor for suspended particulates in Reference 35.

The emission factor for emissions from the baghouse outlet is about 14 g/metric ton (taking the efficiency of collection as 99.8%). This is nearly equal to the MRC value (for total particulate emissions) of 14.5 g/metric ton. This implies that the emissions which are leaving a baghouse, on this type of operation, are still essentially all in the suspendable range. It also implies that in this application the baghouse system does nothing to reduce the emissions leaving the plant boundaries, since the bulk of the previously reported emissions are not transportable by air. At the representative distance of 410 m, particles greater than 20 μm settle and thus do not contribute to the ambient (public exposure) concentrations.

Finally, the purpose of determining an emission factor is to estimate the ambient air concentrations due to several contributors within a source. The sampling method outlined in this report allows a more realistic estimate of source emissions than that previously reported since it is based upon measurements of air concentrations around the contributing source of interest.

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(35) Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. (Final document submitted to the EPA by Monsanto Research Corporation, October 1975.) 109 pp.

APPENDIX E

SOURCE SEVERITY CALCULATIONS

This appendix provides examples of the procedures used to calculate the severity and affected population for free silica particulates, NO_x, CO, and fibers. The effect of growth factor and control technology on emissions is also briefly described.

For ground level sources, the severity for respirable particulates is given as (35):

$$S = \frac{4{,}020\ Q}{D^{1.814}} \qquad \text{(E-1)}$$

Where S = source severity
Q = representative mass emission rate, g/s
D = representative distance from the source, m

For crushed stone operations, the emission factor is 3.25 g/metric ton. The emission rate from a representative plant of 454 metric tons/hr (500 tons/hr) is the product of the emission factor and the production rate:

$$\left(\frac{454 \text{ metric tons}}{\text{hr}}\right)\left(\frac{3.25 \text{ g}}{\text{metric ton}}\right) = \frac{1{,}476 \text{ g}}{\text{hr}} = \frac{0.41 \text{ g}}{\text{s}}$$

At the representative distance of 410 m, the source severity is calculated from Equation E-1 as 0.03.

The distance at which the severity equals 0.1 for respirable particulate is computed from rearranged Equation E-1:

$$D_{S=0.1} = \left(\frac{4{,}020\ Q}{S}\right)^{1/1.814} \qquad \text{(E-2)}$$

$$D_{S=0.1} = \left(\frac{(4{,}020)(0.41)}{0.1}\right)^{1/1.814} = 209 \text{ m}$$

Since this occurs within the plant boundaries, the population affected is zero.

For free silica particulates emitted by ground level sources, the severity is given as (35):

$$S_P = \frac{316\ Q}{TLV \cdot D^{1.814}} \qquad \text{(E-3)}$$

At a mean free silica content of 1.6% by weight (see Table C-4, Appendix C), the threshold limit value is calculated (from Equation B-9, Appendix B) as 2.78 mg/m^3. The source severity is then calculated from Equation E-3 as 0.85.

The distance at which the severity equals 0.1 for free silica particulate is computed from rearranged Equation E-3 to:

$$D_{S=0.1} = \left(\frac{316\ Q}{TLV \cdot S}\right)^{1/1.814} \qquad \text{(E-4)}$$

Therefore, at S = 0.1, $D_{0.1}$ = 1,333 m.

The population affected within the boundary of 410 m to 1,333 m is computed by subtracting the area of a circle with a diameter of 1,333 m from the area of a circle with a diameter equal to 410 m and this is found to be 1.26 km^2. The population affected is the product of the area affected and the population density of 137 persons/km^2, or 172 persons.

The source severity for NO_x is calculated from Equation E-5 (35):

$$S_{NO_x} = \frac{22{,}200\ Q}{D^{1.9}} \qquad \text{(E-5)}$$

Severity is thus 0.089 at 410 m, and the affected population is thus zero. Severity for CO is calculated from Equation E-6 (35):

$$S_{CO} = \frac{44.8\ Q}{D^{1.81}} \qquad \text{(E-6)}$$

The carbon monoxide severity is thus 1.7×10^{-4}.

Severity for fibers is calculated from Equation E-3 described earlier:

$$S_F = \frac{316\ Q}{TLV \cdot D^{1.814}} \qquad \text{(E-3)}$$

Using an emission factor of 128×10^6 fibers/metric ton for the 454 metric ton/hr representative plant, and using the TLV for asbestos fibers of 5 fibers/ml, the severity is thus 0.019.

The growth factor is computed from the ratio of the 1978 emissions to the 1972 levels. Production for 1978 is first calculated by applying the production increase of 3.5% to 5.0 %/yr (Section VI) to the 1972 production levels. The 1978 production level

is thus a mean value of 1.373×10^8 metric tons. The 1978 emissions are calculated by applying the best available control technology. The efficiency of this control technology is applied to the emission factors for each of the unit operations (see Table 1).

As shown in Section V, the best control technology for crushing and screening operations, which have a composite emission factor of 14.47 g/metric ton, is wet suppression. Properly installed suppression systems can attain efficiencies of 99.8% (by weight). The crushing and screening emission factor could therefore be reduced to 0.03 g/metric ton.

The use of water-filled plastic bags may reduce blasting emissions up to 80% for a possible reduction of the emission factor from 0.052 g/metric ton to 0.01 g/metric ton.

The drilling emission factor was calculated for wet drilling operations and it will not be reduced from 0.158 g/metric ton.

Wet suppression systems applied to conveying operations can reduce emissions up to 95%. Their emission factor thus becomes 0.09 g/metric ton.

Transport on unpaved roads is controlled by wetting the surface, and the emission factor for this operation was computed for a wetted road; it will thus remain unchanged.

No feasible (economical or practical) controls are available for loading or unloading trucks or for quarrying.

The new emission factor for total particulates, after applying the best control technology available, is 12.23 g/metric ton. This represents a 57% reduction of the 28.36 g/metric ton 1972 level. Multiplying the 1978 production level of 1.373×10^8 metric tons by this factor yields emissions of 1,679 metric tons/yr of total particulates in 1978. The ratio of 1978 to 1972 emissions (with controls applied) is thus 0.55.

GLOSSARY

amorphous: Without stratification or other division; uncrystallized.

ANFO: Ammonium nitrate and fuel oil mixture used as an explosive.

azimuth: Horizontal direction expressed as the angular distance between the direction of a fixed point (as the observer's heading) and the direction of the object.

basalt: Hard, heavy, dark volcanic rock, sometimes found in the form of columns.

calcareous marl: Crumbly soil consisting of clay, sand and calcium carbonate.

cone crusher: Vertical shaft crusher having a conical head.

confidence interval: Range over which the true mean of a population is expected to lie at a specific level of confidence.

criteria pollutant: Pollutant for which ambient air quality standards have been established.

cutback asphalt: Cement which has been liquefied by blending with petroleum solvents, as rapid curing and medium curing liquid asphalts.

diabase: Dark colored igneous rock made up largely of augite and feldspar.

dustiness index: Reference used in measuring the amount of dust settled where a material is dropped in an enclosed chamber.

dynamite: Powerful explosive of nitroglycerin soaked into an absorbent.

emission burden: Ratio of the total annual emissions of a pollutant from a specific source to the total annual state or national emissions of that pollutant.

fibrosis: Abnormal increase in the amount of fibrous connective tissue in an organ or tissue.

free silica: Crystalline silica defined as silicon dioxide (SiO_2) arranged in a fixed pattern (as opposed to an amorphous arrangement).

granite: Very hard igneous rock, usually gray or pink, consisting chiefly of crystalline quartz, feldspar, and mica.

graphite: Soft, black, lustrous form of carbon.

gyratories: Crushers that move in a circular or spiral path.

hazard factor: A measure of the toxicity of prolonged exposure to a pollutant.

igneous: Produced by the action of fire, formed by volcanic action or great heat.

jaw crushers: Crushers that give a compression or squeeze action between two surfaces.

lignin sulfonates: Organic substances forming the essential part of woody fibers introduced into the sulfonic group by treatment with sulfuric acid.

limestone: Rock consisting mainly of calcium carbonate.

marble: Hard crystalline or granular metamorphic limestone.

metamorphic: Changed in structure by pressure, heat, chemical action, etc.

mica schist: Group of minerals that crystallize into thin, easily separated layers.

noncriteria pollutant: Pollutant for which ambient air quality standards have not been established.

Precipitation-Evaporation index: Reference used to compare the precipitation and temperature levels of various P-E regions of the U.S.

processing plant: That portion of the quarry where the operation of crushing and size classification of stone occurs.

pulverizer: Crusher used to reduce stone size into powder or dust.

quarry: Term used to refer to the mining, processing plant, and material transfer operations.

representative source: Source that has the mean emission parameters.

respirable particulates: Those particles with a geometric mean diameter of ≤ 7 µm.

riprap: Large, irregular stone (>4 in.) used in river and harbor work and to protect highway embankments.

rock: Stone in a mass.

sandstone: Common sedimentary rock consisting of sand grains, usually quartz, cemented together by silica, lime, etc.

scalping screen: Screen used to prescreen the feed to crushers.

sedimentary: Matter or mass deposited by wind or water.

serpentine: A mineral, magnesium silicate, usually green or brownish red; often mottled.

severity: Hazard potential of a representative source defined as the ratio of time-averaged maximum concentration to the hazard factor.

shale: Fine grained rock formed by the hardening of clay which splits into layers when broken.

shell marble: Crystalline or granular metamorphic limestone with a hard outer coating.

shortheads: Refers to a cone crusher.

shuttle conveyor: Conveyor used to move crushed stone back and forth between operations.

silicosis: Chronic disease of the lungs caused by the continued inhalation of silica dust.

silt-sized: Fine particle sized, as soil or sand.

sizing screen: Mesh used to separate stone into various sizes.

slate: Hard, fine-grained rock that cleaves naturally into thin, smooth-surfaced layers.

stone: Hard, solid, nonmetallic mineral matter of which rock is composed.

surge pile: Stockpile near a crusher used to accomodate crushed stone that cannot be transported away fast enough.

thixotropic: Relating to a property of gels to become liquid when shaken or disturbed.

threshold limit value: The concentration of an airborne contaminant to which workers may be exposed repeatedly, day after day, without adverse affect.

traprock: Dark, dense and fine-grained igneous rock.